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COgnitive radio systems for efficient sharing of TV white spaces in EUropean context

D4.1
Spectrum measurements and anti-interference spectrum database specification

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Abstract:
This deliverable D4.1 summarises the results of Task 4.1 and Task 4.2 which address the TVWS characterisation based on off-air measurements and the specification of a geo-location spectrum database, respectively. The off-air spectrum occupancy measurements are carried out in different locations. From the measurement results, conclusions are drawn to describe TVWS which can be released to secondary users dependent on certain criteria. The list of protection criteria together with information on the allocation of frequency channel to incumbent systems are the basis for the COGÉU database specification.

Keyword list: TVWS characterization, spectrum measurement, anti-interference, spectrum database, geo-location
Executive Summary

This deliverable addresses two main tasks, the characterization of TV White Spaces in COGEU scenarios and the specification of the project's geo-location spectrum database. Following the key conclusions/achievements in each task is summarized.

Key Conclusions

On the spectrum measurements and TVWS characterization:

- To describe TVWS in a specific area the total amount of white space available in MHz is not enough. COGEU introduces a new metric to quantify the fragmentation level of TVWS opportunities. Correlation between TVWS and population density is also considered.
- Due to the vast number of possible combinations of TV channels, locations of receivers and locations of WSD (White Space Devices), the direct measurements of TVWS is a cumbersome task. Measuring white spaces is only possible for some few locations, therefore combination with simulation models is required.
- The required parameters and the procedure to investigate the amount of TVWS using simulation is detailed. Computation of TVWS is a computational intensive task. Simplifications are proposed to get a procedure that allows estimating white spaces with a reasonable effort in a reasonable time.
- With a possible WSD transmit power of 1 W (30 dBm) a safety distance of approx 10 km is needed to protect DVB-T receivers in the border of the coverage area. A coverage area for 70% interference margin (acceptable DVB-T reception condition) together with this 10 km width for the safety belt around the coverage area will be used to calculate white spaces for each channel 40 to 60 (COGEU range).
- A strong WSD transmitter in the vicinity of a DVB-T receiver, transmitting on a different channel may corrupt the receiving abilities up to any reception becoming impossible. Measurements of the overload threshold of a DVB-T receiver in the presence of LTE signals are presented for 3 kinds of commercial DVB-T sets.
- Regarding PMSE in the TVWS estimation: with the known location of PMSE equipment, its working range, a margin for location accuracy plus a safety distance for TVWS device transmit power, a circle around each PMSE system is excluded from TVWS map.
- In the vicinity of a strong broadcast transmitter a WSD operating at a different channel may be impaired by DVB-T transmission. For the white space estimation this blocking effect can be taken into account by "punching out" the areas around strong transmitters.
- The interference analysis tool SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool), developed by CEPT, is suitable to investigate the interference between secondary systems operating in TVWS and incumbent receivers (DVB-T and PMSE).
- For LTE over TVWS scenario, SEAMCAT simulations showed that the safety distance around the DVB-T receiver increases as the probability of interference is set to lower values. Moreover, due to the fact that LTE BS are in line-of-sight with the DVB-T aerial antenna, is the LTE downlink that usually limits the white space area (16 km for LTE BS and 4.5 km for LTE UE).
- Using SEAMCAT two detection approaches are simulated and compared: geo-location spectrum database vs. autonomous sensing. Autonomous sensing artificially limits the maximum transmit power allowed for WSD operation due to the high hidden node margin used to protect primary users. Therefore geo-location database allows a more efficient use of TVWS.
- SEAMCAT simulations shows that with one channel separation (8 MHz), an LTE UE can transmit 22 dBm if located at 300 m distance from a PMSE receiver without harmful interference. The safety distance can be decreased to 145 m if 2 channels separation is used. No further improvements are visible by increasing the channel separation above 16 MHz.
- SEAMCAT Technical Group (STG) analyses new features and enhancements from users contributions periodically. Two enhancements related with automatic computation of TVWS maps proposed by COGEU were approved by CEPT and will be available in the next official release of SEAMCAT.
The Rohde & Schwarz ETL TV Analyzer is used by COGEU in the measurements campaign in Munich area. The ETL can read the DVB-T signal Cell ID even at very low power levels, permitting to find the origin of the DVB-T signals. Lab tests showed the Cell ID detection mechanism can detect a DVB-T signal down to 6 dB below the noise floor and its performance does not show any dependency on the propagation profile.

Lab tests with Rohde & Schwarz state of the art spectrum analyzer showed that a threshold level of -110 dBm is a suitable benchmark against which COGEU improvement can be measured.

Spectrum measurements were carried out in order to illustrate how mobility change the received power of DVB-T signals and may influence the ability of WSDs to detect the presence of primary users. It is also illustrated how sensing can exploit past experience taking advantage of spatial diversity brought by mobility.

In an indoor environment, measurements showed that even a few cooperating WSD facing independent fades are enough to achieve practical threshold levels by drastically reducing individual sensing requirements for DVB-T signals.

A spectrum measurement campaign in TV bands was carried out in the southern part of Germany (Bavaria), in urban, suburban and rural areas, within and around Munich. Analysis shows that there are 16 unused channels. If adjacent channels are excluded for TVWS use there remain 8 channels (64 MHz) for potential COGEU operation.

On the COGEU geo-location database specification:

- The main purpose of the COGEU geo-location database is to enable the protection of the incumbent systems (DVB-T and PMSE) from harmful interference.
- The COGEU database is established and updated by national regulators or a third party authorized by the regulators.
- The topology of the COGEU geo-location database is of a two level hierarchy of central database (CDB) holding information for the whole country, and the local database (LDB) with regional white space information. With this design if a change happen in one region the other databases won’t have to be recalculated. This design also offers the flexibility of the deployment of more than one database for one region and thus allows competitive operation of database administrators.
- For the COGEU WSDs a master-slave configuration is envisage, where the master connects to the database and the slaves are managed by the master, without access to the database.
- COGEU devices acquire white space interfaces alongside other more established radio interfaces. COGEU envisage that the initial access to the geo-location database by unlicensed WSD will use existing radio interfaces such as WiFi, LTE or WiMax.
- In COGEU model, the regulatory bodies assign TVWS for spectrum commons (free access) in given areas. The remaining TVWS can be traded in a secondary spectrum market. The design of COGEU geo-location database has to deal with these two operation models. The COGEU geo-location database receives enquires from both, unlicensed WSD’s and from entities running spectrum brokers.
- The COGEU WSDs Broker are prohibited from make use of TVWS until they have successfully determined from the database which frequencies, if any, they are able to transmit on in their location.
- Regulatory enforcement: the national regulator should be in position to stop a secondary transmission in case of interference or allocate TVWS for emergency situations.
- Information on DVB-T incumbents is stable and hence suitable for the spectrum database approach. The same is the case with registered PMSEs, usually for professional applications. COGEU assumes that a database for professional PMSE is either available or will be built up in advance of introduction of white space using equipment. However, the unpredictability of unregistered PMSE applications and Electronic News Gathering, which requires protection, is the main challenge in the design of the COGEU geo-location database.
- The COGEU geo-location database is populated by: Incumbent information (DVB-T and PMSE), Unlicensed WSD information; Broker entity information and Regulatory information. Six COGEU interfaces were identified between the database and external entities.
- COGEU assume a realistic scenario where the regulators will not supply the sensitive data concerning broadcast transmitter parameters. Therefore the regulator would convert the incumbent’s data (confidential raw data) into a list of allowed frequencies and associated transmit powers by performing TVWS calculations.
• COGEU database will provide the “validity period of information” i.e. a period after which a database query should be repeated. This would allow for flexibility and minimisation of the overhead if, for instance, no PMSE users are at the specific location. Note that if time validity is provided then a general update frequency is not needed (2h in initial OFCOM proposal).
• COGEU will use a grid size of 200m x 200m to keep complexity in a reasonable size.
• Each pixel has associated an operation “Mode” field, in order to make clear if a specific entry will be used by the Broker or by the spectrum of commons model.
• All the calculations of TVWS maps are done within the database. Therefore the WSD\Broker is able to call for the available frequencies and allowed transmitter power immediately without calculating by its own.
• Time dependency is one important aspect of the datasets managed. Whereas the DVB transmitter data are very static, PMSE data may show different behaviour. To avoid short update cycles for the transfer of TVWS maps to the WSD\Broker, and therefore to reduce unnecessary efforts for communication, COGEU database divide the PMSE data in two classes: static and non static.
• The complexity of the database is due to datasets relationships, as well as the complexity of TVWS calculations which prevent ‘on the fly’ update of white spaces information. The COGEU approach is to perform the calculations in advance for static systems (DVB-T and some PMSE applications) so as to reduce complexity.
• COGEU will adopt Internet-based protocols and standard enquiry languages. The proposed database access procedure includes XML through web services.
• Cross-border issues have to be considered in the specification of the database. A single centralized European wide database is preferred, since it facilitates the database management in cross-border cases. However this is not easy since each country controls its own information on white space usage. The problem is solvable only by multilateral roaming agreements and international legal frameworks.
• It would also seem sensible to co-ordinate a minimum harmonised standard for the geo-location database(s) and that would allow the safe and widespread adoption of WSDs across Europe. If different database standards were to be used in different countries this would likely result in an enhanced risk of harmful interference which must be avoided.
• In COGEU context, assisted-GPS technology will be adopted in order to overcome problems with low signal levels, enabling also the usage of secondary systems devices in indoor environments.
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COGEU successful operation requires the characterization of the TV white spaces that is the basis for populating the geo-location database. D4.1 reports on the results of the work carried out in tasks T4.1 (TV White Space characterization) and T4.2 (Anti-interference spectrum database specification).

This deliverable is divided into two main chapters. Chapter 2 addresses the characterization of the TVWS and Chapter 3 addresses the specification of the COGEU geo-location database. In short, the contents of each chapter are given below.

For the characterization of TV White Spaces, two approaches were pursued. Firstly, an extensive simulation work on the impact of interfering signals in incumbent systems is carried out. The simulation tool for these investigations was SEAMCAT® (supported by CEPT), and the results reported in Section 2.2-, include the computation of TVWS maps taking into account protection requirements of DVB-T and PMSE (wireless microphones).

The second approach is based on the analysis of the results of measurements in the field and in the lab. The field, spectrum occupancy measurements were carried out in Germany and Portugal, in urban, sub-urban and rural environments. Section 2.3- summarises the results of these measurements including preliminary conclusions about TVWS availability in Munich area. The lab measurements focused on the establishing of currently available sensing techniques for DVB-T and PMSE signals and the definition of appropriate thresholds for which these sensing tools can be operated.

Unlike the unlicensed use of TVWS, currently proposed by regulators such as FCC, OFCOM and CEPT, COGEU project goes beyond the spectrum unlicensed model and proposes a secondary spectrum trading of TVWS. In COGEU model, the regulatory bodies assign part of the available TVWS for spectrum commons (free access) in given areas. The remaining TVWS can be traded in a secondary spectrum market using a centralised broker. Therefore, the COGEU geo-location database receives enquires from both, unlicensed WSD’s and from entities running spectrum brokers, as shown in Figure 1. The design of COGEU geo-location database has to deal with these two operation models.

Chapter 3 discusses the COGEU database topology and interfaces, database parameters, cross-border issues as well as complexity mitigation and practical considerations. Moreover, Chapter 3 proposes a methodology that would enable the COGEU database to derive the list of frequencies that could be available for WSDs/Broker from the information provided about incumbent users (DVB-T, PMSE) and regulators.

The deliverable ends with the conclusion, and future works, which connects to other COGEU tasks.

![Figure 1 COGEU geo-location spectrum database and the two spectrum sharing regimes considered by COGEU: spectrum commons and secondary spectrum market.](image-url)
2- **TV White Spaces characterization**

2.1- **Methods to evaluate TVWS**

In the Introduction of CEPT report 24 [1] the term “White Space” is defined as “a label indicating a part of the spectrum, which is available for a radio communication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other services with a higher priority on a national basis.”

For the investigation of the amount of available white spaces several aspects have to be considered from CEPT definition:

- **“At a given time”**
  Within the considered UHF bands terrestrial TV broadcast and PMSE (mainly wireless microphones) are the incumbent services. Radio Astronomy Services is on channel 38 and therefore below the channels 41-60 considered by COGEU applications.
  For the case of TV transmitters the channel occupation, i.e. which channels are used and which ones are free, is constant over time (in the sense of weeks, months or even years – as long as no TV transmitter parameters are changed or a new transmitter is switched on).
  For the case of PMSE things are not as easy because especially in case of “breaking news” events PMSE equipment may be operated everywhere and at any time. So there is some information required (either gained by sensing, from a geo-location database or via beacon) on the occupation of a channel by PMSE equipment.

In the following only TV broadcast is considered. PMSE protection can be included easily with the same tools if the locations of PMSE (and additional parameters) are known.

- **“In a given geographical area”**
  Whether a geographical area is available for White Space Devices (WSD) radio communication is not a question to be easily answered with yes or no. *The signal strength has to be measured at different locations around a given location and the values have to be compared with a certain level, defined by the incumbent systems parameters.* If in more than say 70%, 90% or 95% of the cases the measured signal strength exceeds the threshold, then the area belongs to a 70%, 90% or 95% coverage.

  In case of propagation calculation for determining the coverage usually cells of the size 100m x 100m, 200m x 200m or 500m x 500m are used. A geo-location database would work with such a grid.

- **“On a non-interfering basis”**
  WSD operation within the UHF bands may be permitted if (and only if) incumbent services are not corrupted by WSD. *To protect incumbent services against interferences from WSD, depending on the transmit power of the WSD, a minimum distance to the closest possible receiver working at the considered channel, is required.* But WSD do not have a mean to detect purely passive TV receivers in their vicinity, even if they are only few meters away.
  Due to this, operation of a WSD on a channel N being within the coverage area of any incumbent service active at this channel is excluded [3].
  Furthermore, for reasonable transmit power (e.g. 0 dBm or more) outside the coverage area for the WSD a safety distance (“safety belt”) around the coverage area is needed.

  In case of “sensing only” of the WSD in addition a Hidden Node Margin (HNM) has to be taken into account.

  For adjacent channel operation (i.e. channel N being free but channels N±i with i = 1, 2... may be used by incumbents) the maximum transmit power of the WSD may be further reduced.

1 see sec. 4.3.3 where this operational condition is derived for autonomous sensing devices. For geo-location/database system exclusion areas (coverage areas) are inherently contained.
On a non-protected basis

WSD has to accept interference caused by TV transmission and/or PMSE operation.

- If PMSE is detected, WSD has to stop transmitting in this channel immediately.

- In case of very strong signals in channels adjacent to the WSD, the input amplifier of the WSD may be blocked by these signals. Therefore locations close to broadcast transmitters may not be usable by WSD and reduce the amount of available White Space.

The most realistic way to get information on available TVWS would be to measure the received signals at the locations of broadcast receivers, see Figure 2.

However, this would require for each possible broadcast receiver position to measure the interference from any possible WSD (Cognitive Radio) at any location. If the interference at each receiver position, where broadcast reception is possible for the considered channel, remains below a given threshold, then this WSD position belongs to a White Space area. The vast number of possible combinations of channels, locations of receivers and locations of WSD makes this an unsolvable task.

As an approach the coverage area of the broadcast transmitters for all channels could be measured. Together with a safety belt around the coverage area, depending (among others) on the transmit power of the WSD and the acceptable additional interference caused by the WSD to the incumbent services, an estimation on available White Spaces could be gained. But even this would be a cumbersome task as each channel and the whole area (country, nation…) would have to be measured.

So, measuring white spaces is only possible for some few locations. In section 2.3- a measurement campaign around Munich/Germany is described.

### 2.1.1- Parameters for calculation of the amount of available TV White Space

For estimating the amount of TVWS a number of parameters has to be fixed.

#### 2.1.1.1 DVB-T system variant

The White Space investigations are planned for Munich, Germany, where the prevalent system variant is 16 QAM 2/3. With the parameters for this system variant the coverage areas for all broadcast transmitters and all channels are calculated with IRTs frequency planning software FRANSY in the following way:

To calculate the location probability for a given site for a large number of locations within a small area ("pixel"), e.g. 200m x 200m around that site a simulation is made as depicted in Figure 3:
2.1.1.2 Interference Margin

A WSD transmitter being in the vicinity of the coverage area of a broadcast transmitter and using the same channel may impair the reception conditions for TV receivers and so reduce the coverage. Therefore the demanded “non interference basis” operation is in principal not possible. To limit the degradation of TV reception an acceptable reduction of the coverage has to be fixed, e.g. from 95% to 94.9%. 

Figure 3 Principle for calculation of location probability

- Select randomly a location within the small area
- Calculate the field strength $E^w$ of the wanted broadcast signal
- At the same location take the noise level, add the protection ratio and the calculated interference strength for each interfering signal to get the unwanted field strength $E^I$ (the nuisance field)
- Repeat these steps n times
- If $E^w > E^I$ in more than a predefined value of the locations, e.g. 95%, the pixel is part of coverage area

If the coverage area for a given location probability (e.g. 70%) is calculated, it should be kept in mind that broadcast reception is also possible outside this 70% coverage area. It is just possible with a lower probability (e.g. 50%) what means that maybe the antenna position has to be varied to get an appropriate signal. Figure 4 shows an example for two coverage areas for adjacent SFN (Single Frequency Network). In the white areas the location probability is higher than 99% in the black areas it is below 50%. The colored areas show cells where location probability decreases (green → yellow → red → gray).

Figure 4 Example for different location probabilities in a coverage area
For the case of a WSD operated outside the coverage area a simulation for each possible location would be required to find the degradation of coverage. As this is extremely time consuming a simpler approach is to assume that the system is noise limited and use field strength values instead of location probabilities.

This approach neglects that at an interference limited location the minimum required DVB-T signal strength has to be higher than in the noise limited case. As a consequence, the permissible interference power of a WSD at this location could also be higher. Therefore in the interference limited case, the safety distance could be shorter: using the safety distance for noise limited area is the worst case consideration.

For the simplified noise limited model, the interference margin (IM) is an appropriate parameter to describe additional interference caused by WSD. It defines the maximum additional interference relative to the noise level. If for example a degradation of the receiver sensitivity of 0.5 dB would be accepted, i.e. $N+I=-97.5$ dBm for $N=-98$ dBm, the interference margin is -10 dB which means the WSD may generate an interference signal 10 dB below noise at the location of the TV receiver.

### 2.1.1.3 WSD transmit power and safety belt

With the minimum field strength at the edge of coverage, the protection ratio (this value also depends on the signal structure of the WSD signal and may for co channel case exceed the 21 dB value for DVB-T interfering with DVB-T) and the interference margin the acceptable WSD signal strength at the location of a broadcast receiver can be calculated. With a maximum transmit power for the WSD (and other parameters describing the signal propagation) the minimum distance between WSD and TV receiver can be estimated.

Bearing in mind that the WSD transmit powers are moderate (typ. less than 30 dBm) the safety distance is expected not to be very large. To take into account that over a realistic terrain the attenuation is higher than for free space propagation, for the considered distances a simple propagation model is applied. It assumes for the attenuation depending on the distance:

<table>
<thead>
<tr>
<th>Distance</th>
<th>Attenuation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 100 m</td>
<td>20 dB/decade (free space propagation)</td>
</tr>
<tr>
<td>100 m ... 1000 m</td>
<td>30 dB/decade</td>
</tr>
<tr>
<td>Above 1000 m</td>
<td>40 dB/decade</td>
</tr>
</tbody>
</table>

![Figure 5: Simple propagation model for short distances.](image)

Example:
- WSD transmit power: 30 dBm, IM = -10 dB $\rightarrow$ $I = N-10$ dB = -108 dBm
- Path loss: -138 dB

This requires a safety distance of approx 10 km.
2.1.1.4 Hidden Node Margin

If sensing is relevant for the system and sensing is done with mobile terminals (at low height) a Hidden Node Margin (HNM) may be necessary to protect incumbent services. (For WS base stations the hidden node may not be necessary as they are mounted at higher locations.)

As specified by COGEU reference model (see deliverable D3.1) the COGEU system will have to contact a database to get channel information and may use sensing only as an additional means to make sure that incumbents are not interfered, HNM is not treated in this considerations.

2.1.1.5 Adjacent channel situation

So far only the situation where TV and WSD operate on the same channel was considered. In case of adjacent channel operation (i.e. broadcast transmitter operating on channel N and WSD transmits on channel N+i with i = 1, 2…) the WSD is inside the coverage area of channel N (if outside, the adjacent channel would be free by definition). Depending on the Adjacent Protection Ratio PR$_{adj}$, the maximum transmit power may be reduced (Protection Ratios are defined in deliverable D3.1).

2.1.1.6 Blocking of WSD in the vicinity of broadcast transmitters

If the WSD receives a strong signal on an adjacent channel, due to nonlinearities of the input amplifier the WSD may be blocked. As WSD usage is on a “non protected” basis, operation of a WSD in the vicinity of broadcast transmitter may become impossible. This effect also may reduce the amount of available white space.

2.1.2 Procedure to compute the amount of TVWS

For each channel $N=40$ to 60 within the considered band 622 – 790 MHz a calculation is made for a coverage of 70% (Geneva 06: “acceptable reception condition”). The area outside the coverage areas of the different transmitters is a kind of “gross white space”. Around each of the coverage areas a safety distance (safety belt) is taken, depending mainly on the WSDs transmit power. This gives the TVWS for each single channel.

In a second step adjacent channel effects are taken into account:
- Usage of adjacent channel by incumbent services may reduce the possible transmit power of WSD
- A strong broadcast transmitter in the vicinity may overload the WSD and prevent WSD operation

2.1.3 Metrics for TVWS availability

To describe TVWS availability, the maximum possible WSD transmit power shall be plotted against the frequency (channel number) for each location. This allows to measure the maximum available bandwidth (8 MHz, 16 MHz, 24 MHz, …) and so the amount of TVWS at this location. Integration over all locations gives the total amount of white space in the area considered.

However, the total amount of TVWS at a location is not enough to describe the situation: the available channels may either be separated from each other or there may be some channels being contiguous. Figure 6 shows a situation with two blocks of 4 channels (ch. 40-47 and 50-53), one block consisting of 3 channels (57-59) and one isolated channel (ch.40). Figure 7 shows an example where TVWS is highly fragmented.
Considering TVWS applications that need more bandwidth than being available in one TV channel, e.g. LTE needs up to 20 MHz, which requires 3 contiguous channels, it becomes clear, that contiguous channels are more attractive than fragmented spectrum. This is also relevant if free channels adjacent to TV channels may only be used with a lower transmit power.

To take this into account in the description of available spectrum, two parameters are considered necessary:

1) The total amount of TVWS at this location
   In Figure 6 this is 96 MHz (12 channels = 1 + 4 + 4 + 3)
   In Figure 7 this is 80 MHz (10 channels = 1 + 1 + 2 + 2 + 1 + 1 + 2)

2) The level of fragmentation

To describe the fragmentation it is believed that the opposite, i.e., a kind of "compactness", would be the better parameter. To characterize this we use the following policy:

To describe the situation the available blocks are listed in a descending order, e.g. for

Figure 6: (4, 4, 3, 1) \{sum = 12\}
Figure 7: (2, 2, 2, 1, 1, 1) \{sum = 10\}

For a location with e.g. 5 unused channels, the following combinations would be possible:

| a) | 1 | 1 | 1 | 1 | 1 | no contiguous channels at all |
| b) | 2 | 1 | 1 | 1 |
| c) | 2 | 2 | 1 |
| d) | 3 | 1 | 1 |
| e) | 3 | 2 |
| f) | 4 | 1 |
| g) | 5 | 5 contiguous channels |
To derive a parameter to prize the compactness of spectrum we introduce a weight function for the separate blocks and sum up all the values.

\[ \text{sum} = \text{total sum of available channels, as described above (Figure 6: 12, Figure 7: 10)} \]
\[ b(i) = \text{width of block } i, \text{ e.g. in Figure 6: } b(1) = 4, b(2) = 4, b(3) = 3, b(4) = 1; \]

with this:

\[
\text{sum} = \sum_{i=1}^{n} b(i)
\]

For the weight function we propose:

\[
w(b) = \frac{b^2}{\text{sum}^2}
\]

For the level of compactness (\( \text{comp}' \)) we then find:

\[
\text{comp}' = \sum_{i=1}^{n} w(b(i))
\]

In we do have e.g. \( n=8 = \text{sum} \) then \( \text{comp}' \) is between 0.125 for 8 isolated channels and 1 for one contiguous block. In general, all values lie between \( 1/n \) and 1. To scale this to \([0...1]\) the following transformation is used:

\[
\text{comp} = \frac{\text{comp}'}{1 - \frac{1}{n}}
\]

The following table shows all possible combinations of 8 channels and the calculated compactness.

<table>
<thead>
<tr>
<th>Compactness</th>
<th>[%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>0.0</td>
</tr>
<tr>
<td>0.036</td>
<td>3.6</td>
</tr>
<tr>
<td>0.071</td>
<td>7.1</td>
</tr>
<tr>
<td>0.107</td>
<td>10.7</td>
</tr>
<tr>
<td>0.107</td>
<td>10.7</td>
</tr>
<tr>
<td>0.143</td>
<td>14.3</td>
</tr>
<tr>
<td>0.143</td>
<td>14.3</td>
</tr>
<tr>
<td>0.179</td>
<td>17.9</td>
</tr>
<tr>
<td>0.214</td>
<td>21.4</td>
</tr>
<tr>
<td>0.214</td>
<td>21.4</td>
</tr>
<tr>
<td>0.250</td>
<td>25.0</td>
</tr>
<tr>
<td>0.250</td>
<td>25.0</td>
</tr>
<tr>
<td>0.286</td>
<td>28.6</td>
</tr>
<tr>
<td>0.321</td>
<td>32.1</td>
</tr>
<tr>
<td>0.357</td>
<td>35.7</td>
</tr>
<tr>
<td>0.393</td>
<td>39.3</td>
</tr>
<tr>
<td>0.429</td>
<td>42.9</td>
</tr>
<tr>
<td>0.464</td>
<td>46.4</td>
</tr>
<tr>
<td>0.536</td>
<td>53.6</td>
</tr>
<tr>
<td>0.571</td>
<td>57.1</td>
</tr>
<tr>
<td>0.750</td>
<td>75.0</td>
</tr>
<tr>
<td>1.000</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 1 shows that the poorest case (only separated channels) is prized with the value 0 and the best case of 8 contiguous channels is 1. For the values in between the compactness should increase with the width of the blocks, which is the case.

**With this we do have a tool to describe and compare level of compactness.** From Table 1 it can also be seen that there are different combinations with the same compactness for example combinations (3, 3, 1, 1) and (4, 1, 1, 1, 1). The used weight function is one example which is used due to its simplicity. Further studies and increasing knowledge of spectrum occupation and hence TVWS channel distribution could require to modify the weight function to get a better description at a later stage of project.

The proposed methodology enables us to describe the TVWS situation at a given location with two parameters: (sum, comp).

As a further parameter describing the value of TVWS the number of possible users at a location is very important. For instance, free channels available in a very sparsely populated area of low value. So far the white spaces are mapped to the area. A more reasonable information may be to map them to the population density as this better reflects the value of available spectrum to be traded by the COGEU broker.

In WP6 (T6.5.1) the available TVWS in the Munich area shall be identified. It is intended to map to area and also to map to population density and compare the results to find an appropriate way to describe and prize the TVWS for given locations.

### 2.1.4- Practical considerations for estimation of TVWS

Section 2.1- has shown that starting from calculated coverage areas gives a practical means to estimate the available TVWS. **It was pointed out that some simplifications are necessary to get a procedure that allows estimating white spaces with a reasonable effort in a reasonable time.** The COGEU demonstrator and TVWS computation are planned for Munich, Germany, where the prevalent system variant is 16QAM 2/3. The considered scenario is fixed rooftop.

Besides DVB-T, PMSE is the second incumbent system in the Munich area. If the location of all PMSE equipment is known, its effect on the availability of TVWS can easily be taken into account: For PMSE equipment the transmit power usually is fairly low (e.g. 50 mW) and therefore the working distance between PMSE transmitter and receiver is limited to some 100 m. **With the known location of PMSE equipment, its working range, a margin for location accuracy plus a safety distance for TVWS device transmit power a circle around each PMSE system is excluded from TVWS map.**

#### 2.1.4.1 Co-channel interference

**Noise limited system**

If a transmitter is operating without any interference from other transmitters using the same channel then, the minimum field strength for a given location probability is (according to deliverable D3.1, section 4.4.1.1) done by:

\[
E_{\text{min},lp,N} \left[ \frac{dBm}{m} \right] = 77.21 dB + 20 \log(f [MHz]) + P_{\text{sense}} [dBm] + \omega_{lp} \sigma_w - G_{i,r} [dBi]
\]

For \( f = 690 \ MHz \), \( P_{\text{sense}} = -98.17 \ dBm + 21 \ dB \) (for fixed reception), \( \sigma_w = 5.5 \) and \( G_{i,r} = 9.15 \ dB \) the minimum mean field strength \( E_{\text{min},lp,N} \) becomes for different location probabilities:
Therefore, in order to enable DVB-T decoding in 70% of the locations of a pixel, the mean field strength has to be at least 50.55 dBµV/m. In the noise limited case the coverage area for a 70% location probability is bordered by this field strength level of 50.55 dBµV/m.

**Interference limited system**

If other transmitters are active in the same channel then, depending on the distance, the noise level \((N+I)\) at the location of the (interfered) receiver increases. To get the same location probability at this location a higher field strength is required: \(E = (N+I) + PR\).

As the interfering signal \("I"\) decreases with increasing distance to the interfering transmitter, for sufficient distances the interference \(I\) can be neglected and at these locations the noise limited approach would be justified.

**Simplified model / Assumptions**

IRT’s frequency analysis software FRANSY is used which takes topography as well as morphography into account. The coverage areas are calculated for 70% location probability. According to GE06 a 70% location probability is called acceptable reception condition.

Single Frequency Networks (SFN) are considered where available transmitters not belonging to the same SFN cause interference signals to the other transmitters.

To calculate the TVWS within a channel some assumptions and simplifications are made:

- It is assumed that broadcast reception is possible inside 70% coverage areas but not outside (i.e. neglecting all the areas where broadcast reception with a lower location probability is possible).

- The same safety distance is used for all locations around the broadcast coverage areas. This covers two assumptions:
  - The coverage area is treated as if being noise limited i.e. the minimum mean field strength at the edge of coverage is assumed to be 50.55 dBµV/m
  - For the TVWS device topography and morphography are neglected and the simple propagation model described in section 2.1- is used.

**Interference Margin**

CEPT WG SE42 considers for the coexistence of services with the same priority \(IM = -6\) dB. ITU WP 1A recommends for PLT (power line technology) -10 dB [56]. ITU-Rec. BT 1786 [57] recommends that the total interference to broadcasting from ultra-wideband devices (UWB) should “at no time exceed one percent of the total receiving system noise power” [58], i.e. \(IM = -20\) dB.

As the TVWS device applications do have a lower priority than the incumbent services, it is appropriate here also to use \(IM = -20\) dBm. ²

---

² In an input document for CEPT WG SE43 [59] it is derived that \(IM = -20\) dB causes a degradation of location probability from 95.0% → 94.9%.
Antenna gain
The considered scenario is “fixed rooftop”. In this case it can be assumed that directional antennas are used (at least in the case of being close to the edge of the coverage area where signal is poor) and that these antennas are directed to the broadcast transmitter, i.e. to the center of the coverage area. Any signal from a WSD transmitting outside the coverage area is seen by the antenna “from behind”.\(^3\)

TVWS device transmit power
So far, in Europe an upper limit for the maximum transmit power of TVWS devices is not (yet) fixed. In the USA the FCC allows 4 W EIRP for fixed stations and 100 mW for portable devices. As ordinary cellular phones also have a transmit power below 1 W it seems to be reasonable to use 1 W EIRP for WSD for the investigations made here.

Putting values together
Minimum field strength at the edge of coverage \(E_{\text{min},95,N}\) \(= 50.6\,\text{dBµV/m}\)
Protection Ratio (for DVB-T interfered with by DVB-T) \(= 21.0\,\text{dB}\)
Interference margin \(= -20.0\,\text{dB}\)
Antenna reverse discrimination \(= -16.0\,\text{dB}\)
Max. acceptable interference field strength: \(= 25.6\,\text{dBµV/m}\)

For a frequency of 690 MHz this corresponds to -110.5 dBm. With a possible WSD transmit power of 1 W (30 dBm) the path loss is -140 dB. Applying the simple propagation model from D4.1 chapter 2.1- Figure 5 the safety distance becomes \(\approx 10\,\text{km}\).

So, coverage area for 70% interference margin together with this 10 km width for the safety belt around the coverage area will be used to calculate white spaces for each TV channel 40 to 60 (COGEU target).

2.1.4.2 Adjacent channel interference
As a consequence of the “non interfering basis” of WSDs, within the coverage area of a broadcast transmitter, transmission (in the same channel) is excluded. Considering adjacent channels (i.e. WSD transmitting on channel \(N\) and broadcast transmitter operates on channel \(N\pm i\) with \(i = 1, 2\ldots\)) to the WSD channel, different cases have to be considered:

a) If the WSD location is outside the coverage areas of all adjacent channels \(N\pm1,2\ldots\), then the channel at this location can be considered (unlimited) free, i.e. no additional limitations caused by adjacent channels.

b) WSD is inside coverage area of at least one adjacent channel \(N\pm1,2\ldots\).

i. Portable indoor /portable outdoor coverage area
   In this case the WSD and TV receiver may be in close vicinity, e.g. 3 m. (For even smaller distances it can be assumed that TV user and TVWS device user is the same person and can suppress interference by its own.)
   The path loss in this case is \(-38.8\,\text{dB} + 2\times 2.15\,\text{dBi}\) for dipole antennas: \(p_l = -35\,\text{dB}\).

ii. Fixed rooftop reception
   The Yagi antenna is assumed to be on a mast at a 10 m height and the TVWS device may be at a similar height (e.g. in the 3rd floor of a building) in a distance of approx. 10 m to the mast in the main lobe of the Yagi antenna.
   Here the path loss is \(-49.2\,\text{dB} + 2.15 + 9.15\,\text{dB}\) for a Yagi antenna: \(p_l = -38\,\text{dB}\).

\(^3\) Isolated coverage areas, e.g. on hilltop and concave coverage areas are for reasons of simplicity not considered here.
This means that the acceptable transmit power of a TVWS device in a PI/PO coverage area is 3 dB lower than outside that area but still inside fixed rooftop coverage area. As the value does only determine the maximum permissible transmit power and not the amount of white spaces, to avoid unnecessary complication we use path loss of -35 dB for both cases.

The influence of an interferer into a victim system is described by the Protection Ratio (see D3.1, section 4.1), in case of adjacent channel N+i: PR_{i}. The values depend on the channel separation and on the type of interferer. Values for LTE and WiMAX are given in COGEU D3.1.

For LTE as an interferer values range from -20 dB for small frequency offsets down to -30 dB for large offsets (see D3.1- section 4.2 "Compatibility criteria between CR using LTE technology and DVB-T reception"). With a minimum field strength of 51 dBµV/m for fixed TV reception, a PR_{i} = -20…-30 dB and a path loss of -35 dB the max. WSD transmit power becomes:

\[ E_{\text{WSD, max}} = 51 \text{ dBµV/m} + (20…30) \text{ dB} + 35 \text{ dB} = 106 \ldots 116 \text{ dBµV/m} \]

For 690 MHz this corresponds to \( P_{\text{WSD, max}} = -28 \ldots -18 \text{ dBm} \). This rather low transmit power is due to the low PR_{i} values, caused by the spectrum mask. If the LTE and WiMAX spectrum masks were more restrictive such that PR_{i} = -40 dB for i=1 and -60 dB for i≥2 then the maximum transmit power became:

\[ P_{\text{WSD, max}} (i=1) = -8 \text{ dBm} \]
\[ P_{\text{WSD, max}} (i≥2) = 12 \text{ dBm} \]

Two conclusions can be taken from this:

i) As the protection ratio for i=±1 adjacent channels is limited due to technical reasons, e.g. filters, if operation in N±1 is permitted, it will only be with a reduced transmit power. (FCC allows for adjacent channel i=1 max. 16 dBm [61])

ii) The spectrum mask has to be much more restrictive to reach PR = -60…-70 dB for reasonable transmit powers in N±i, i≥2.

However, applying a more stringent spectrum mask to the LTE emission cannot in general improve the compatibility situation because even at average wanted signal levels, a number of DVB-T receivers already show overload effects that limit the maximum unwanted signal level.

### 2.1.4.3 Overloading DVB-T receivers

A strong transmitter in the vicinity of a broadcast receiver, transmitting on a different channel may corrupt the receiving abilities up to any reception becoming impossible. In this section the COGEU scenario, LTE over TVWS is used to illustrate the overloading effect. Two cases have to be considered:

#### 2.1.4.3.1 LTE base station

Assumptions:

- The LTE BS dipole antenna is mounted on a 10 m mast
- Any DVB-T portable receiver is at least 10 m away
- Fixed rooftop antenna (Yagi) not directing to the LTE BS antenna is at least 10 m away
- Fixed rooftop antenna (Yagi) directing to the LTE BS antenna is at least 20 m away

---

4 For i=±1 (direct adjacent channels) the values for downlink (base station) and uplink (user equipment) are in line with ECC report 148, for larger channel separation however the values are significantly higher. This is because for the measurements made in D3.1-section 4.2 the spectrum mask given in 3GPP TS 36.110 v9.20 was used.
The worst case out of these is the portable receiver. The path loss for free space propagation (690 MHz) is -49.2 dB, with a dipole on each side: \( \approx -45 \) dB

Table 3 Measured overload threshold of a DVB-T receiver in the presence of a LTE base station signal.

<table>
<thead>
<tr>
<th>Channel edge separation (MHz)</th>
<th>O_{th} (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90th</td>
<td>50th</td>
</tr>
<tr>
<td>Can STB/STV/DTV</td>
<td>Silicon STB/STV/DTV</td>
</tr>
<tr>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td>25</td>
<td>8</td>
</tr>
<tr>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>41</td>
<td>8</td>
</tr>
<tr>
<td>49</td>
<td>5</td>
</tr>
<tr>
<td>65</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 3, taken from ECC report 148 (Table 5b) [62] shows the measured overload threshold for a LTE base station considering 3 kinds of DVB-T commercial receivers (Can, Silicon STB and Silicon USB)

Notes:
- Measurements were made with 64 QAM 2/3. As the overloading threshold is independent of system variant and reception conditions, no correction factors are required.
- The 90th percentile for the overloading threshold value corresponds to not overloading of 10% of receivers measured with respect to the given frequency offset and parameter (i.e. the 10th percentile for the overloading threshold should be used to protect 90% of receivers measured).

Taking this into account, the measured overload threshold for the 10th percentile range for

Can STB: \(-19 \) dBm ... \(-3 \) dBm
Si STB: \(-13 \) dBm ... \(-6 \) dBm
Si USB: \(-26 \) dBm ... \(-13 \) dBm

With the path loss of 45 dB the allowed base station transmit powers become:

Can STB: max. 26 dBm
Si STB: max. 32 dBm
Si USB: max. 19 dBm

To protect 90% of Si USB devices from overloading, the maximum transmit power for a LTE base station has to be limited to 19 dBm (for higher frequency offset the value can be higher: 26 dBm).
2.1.4.3.2 **LTE user terminal**

Table 4 Measured overload threshold of a DVB-T receiver in the presence of a LTE user terminal signal

<table>
<thead>
<tr>
<th>Channel edge separation (MHz)</th>
<th>90(^{th}) O(_{\text{cl}}) (dBm)</th>
<th>50(^{th}) O(_{\text{cl}}) (dBm)</th>
<th>10th O(_{\text{cl}}) (dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Can STB</td>
<td>Silicon STB</td>
<td>Can STB</td>
</tr>
<tr>
<td>1.5</td>
<td>-11</td>
<td>-14</td>
<td>-16</td>
</tr>
<tr>
<td>9.5</td>
<td>1</td>
<td>-10</td>
<td>-6</td>
</tr>
<tr>
<td>17.5</td>
<td>0</td>
<td>-5</td>
<td>-16</td>
</tr>
<tr>
<td>25.5</td>
<td>-7</td>
<td>-5</td>
<td>-13</td>
</tr>
<tr>
<td>33.5</td>
<td>-1</td>
<td>-5</td>
<td>-9</td>
</tr>
<tr>
<td>41.5</td>
<td>0</td>
<td>-16</td>
<td>-9</td>
</tr>
<tr>
<td>49.5</td>
<td>6</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>57.5</td>
<td>4</td>
<td>-12</td>
<td>-4</td>
</tr>
<tr>
<td>65.5</td>
<td>5</td>
<td>-13</td>
<td>-2</td>
</tr>
</tbody>
</table>

Table 3, also taken from ECC 148 (Table 7b) [62], shows the measured overload threshold for a LTE user terminal. To protect 90% of the receiver (see note above) the values range:

- **Can STB**: -31 dBm ... -3 dBm
- **Si STB**: -47 dBm ... -5 dBm
- **Si USB**: -49 dBm ... -27 dBm

With the path loss of 45 dB the allowed user terminal transmit power become:

- **Can STB**: max. 14 dBm
- **Si STB**: max. -2 dBm
- **Si USB**: max. -4 dBm

To avoid overloading DVB-T receivers under the given assumptions the maximum transmit power for LTE user terminal has to be limited to -4 dBm. It should be mentioned that this is a worst case value as mainly low price consumer equipment was investigated. Besides, it can be seen that second or third generation of Silicon tuner show a much better performance. Therefore, for a realistic time of introduction of WSDs, first generation Si tuners may be a matter of legacy.

### 2.1.4.4 Multiple Interference Margin

So far only the interference of a single TVWS device interfering DVB-T receptions was considered. However, if WSD density increases, multiple interference into a DVB-T receiver cannot be excluded. SE43 proposes for this margin 3 to 6 dB, depending on the number of interferers.

### 2.1.4.5 Location probability with acceptable DVB-T reception

In Germany public broadcasters are obliged to supply broadcast reception for everybody, so public broadcast programs can be received almost everywhere. Private broadcasters however do have to compare the benefit of getting some more consumers with the additional costs for distributing broadcast signals into an area. In most parts of Germany private broadcasters decided only to supply the densely populated cities, e.g. in the Munich area. It should be borne in mind that broadcast reception is also possible outside the 70% coverage area and often people living in adjacent areas use high gain antennas and carefully selected antenna locations to get a sufficient signal. Using TVWS device at these channels in these suburban areas may cause interference into (esp. private) broadcast reception.
2.1.4.6 Considering PMSE in the TVWS estimation

In the beginning of this section it was mentioned that PMSE systems can be protected by a circle around the PMSE equipment with a radius (“safety distance”), mainly dominated by the TVWS transmit power and the protection ratio of PMSE equipment. If, as a first assumption, the same safety distance is taken as for DVB-T, each PMSE removes a circle with radius 10 km from the white space map. This seems to be negligible for the first glance, however two aspects have to be considered:

- A large number of PMSE equipment is in the market;
- PMSE equipment is mostly used in urban areas, i.e. in areas where the available TVWS is already reduced due to the higher number of DVB-T channels.

Considering PMSE equipment in the TVWS estimation is difficult as the locations are not known. PMSE equipment may be taken into account by assuming a statistically distributed number of PMSE over the considered area.

2.1.4.7 Coexistence requirements between secondary users

When considering TVWS applications, a major part of discussion is the protection of the incumbent services (TV broadcast, PMSE, RAS in channel 38 and ARNS in channels 43 to 60), which means avoiding of interference to these services caused by WSD.

COGEU considers the following secondary applications over TVWS as representative:

- LTE standing for exclusive usage of TVWS where a guaranteed Quality of Service is possible under the regime of a spectrum trading. The network topology is ‘cellular net’.
- WiFi as a spectrum commons application with a “best effort” access to spectrum. The topology is ‘ad hoc’ and/or ‘infrastructure (access points)’.
- Public safety applications which get – if required - a higher priority than the other applications. Expected topology is ‘mesh net’.

However, if the TVWS application should operate reasonable or if for some applications even a defined Quality of Service is required, also the mutual interference of different WSD has to be considered. COGEU will investigate coexistence rules between secondary users of TVWS in T4.4 (Testbed for coexistence evaluation).

2.1.4.8 Blocking of TVWS device in the vicinity of broadcast transmitters

In the vicinity of a strong broadcast transmitter operation of a TVWS device operating at a different channel may be impaired by DVB-T transmission. Measurements reported in D3.1- section 4.3.2 for WiMAX show a protection ration $PR_{adj} = -30...-40 \text{ dB}$ for WiMAX signal interfered with by DVB-T signal. For the white space estimation this effect can be taken into account by “punching out” the areas around strong transmitters.
2.2- TVWS statistical characterization based on simulation

TVWS characterization can be done based on exhaustive measurements campaigns (only possible for limited areas), or based on simulation using a statistical interference analysis tool with suitable propagation models. COGEU will combine the two approaches to obtain accurate maps of TVWS in Munich\Germany area. The objective of this section is to study how to derive TVWS maps from interference simulations. The simulation scenario considers primary user DVB-T and PMSE and as secondary user an LTE system operating over TVWS. The generic scenario is as depicted in Figure 8.

![Figure 8 Generic interference scenario.](image)

Specifically, we consider the worst-case scenario geometry where the primary receiver (DVB-T set) is on the border of the coverage area. The interference analysis tool SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool) from CEPT is used to study the interference between secondary systems and incumbent receivers (DVB-T and PMSE). Two detection mechanisms are analysed: autonomous sensing and geo-location database access.

2.2.1- SEAMCAT overview as a tool for interference analysis

SEAMCAT® is a software tool based on the Monte-Carlo simulation method, which was developed within the frame of European Conference of Postal and Telecommunication administrations (CEPT). This tool permits statistical modeling of different radio interference scenarios for performing sharing and compatibility studies between radio communications systems in the same or adjacent frequency bands. The SEAMCAT project is an ongoing WGSE (Working Group Spectrum Engineering) activity. The daily maintenance of the project and the SEAMCAT software is entrusted to the ECO (European Communications Office [4]). STG (SEAMCAT Technical Group) acts as the supervising committee and source of technical expertise. Currently SEAMCAT-3 is the latest official release of SEAMCAT tool. Further updates are possible in the future and ECO welcomes any proposals for implementation of new functionalities in SEAMCAT.

The Monte Carlo technique can address any of the radio interference scenarios regardless of the interfering and victim systems. There is no restriction upon the victim or interfering systems. The only requirement is that there is knowledge of the parameters that can be used to model them. This includes the receiver and transmitter specifications, the propagation model associated with the medium of communication and a measure of the quality of service required. However, SEAMCAT assumes a flat Earth model for calculating path geometries and propagation losses. This limits the range of considered standard interference scenarios to terrestrial configurations and non-path-specific propagation models.

2.2.1.1 Terminology

SEAMCAT defines a victim link and one or more interfering links. As illustrated in Figure 9, a wanted transmitter (Wt) sends a signal (dRSS) to a victim receiver (Vr). An interfering transmitter (It) also emits a signal (iRSS) to a wanted receiver (Wr) that interferes with the victim link.
2.2.1.2 Interference computation

One criterion for interference to occur is for the victim receiver to have a carrier to interference ratio (C/I) less than the minimum allowable value. In order to calculate the victim’s C/I it is necessary to establish the victim’s desired Received Signal Strength (dRSS=C) as well as the interfering Received Signal Strength (iRSS=I). The position of the victim’s wanted signal transmitter is identified and a link budget calculation completed. Having knowledge of both the interfering signal strength and the wanted signal strength allows the victim’s C/I ratio to be computed. Figure 10 illustrates the various signal levels.

The left-hand side of the diagram represents the situation when there is no interference and the victim is receiving the desired signal with some margin. In this case the victim’s C/N ratio is given by the sum of the wanted signal margin and the minimum permissible C/N. The right hand side of the diagram illustrates what happens when interference is introduced. The interference adds to the noise floor and the victim’s C/I ratio is reduced. The number of dB difference between the wanted signal strength and the increased noise floor defines the new C/I ratio. This ratio must be greater than the minimum permissible C/I if interference is to be avoided. The Monte Carlo simulation tool checks for this condition and records whether or not interference is occurring.

Several interference mechanisms are included such as unwanted emissions, receiver blocking, intermodulation products, co-channel and adjacent channel interference phenomena are also considered in the methodology. The level of unwanted emissions falling within the victim’s receiver bandwidth is determined using the interferer’s transmit mask, interferer / victim frequency separation, antenna gains and propagation loss. The receiver blocking power, i.e. the power captured from the on-channel transmissions of the interferer due to selectivity imperfections of the victim’s receiver, is determined using the interferer’s transmit power, victim receiver blocking performance, interferer / victim frequency separation, antenna gains and propagation loss.

2.2.2 Computation of TVWS maps considering geo-location database

In this section the computation of the TVWS maps is performed assuming that the location of the WSD is known together with the transmitter and receiver parameters. As mentioned in D3.1, the COGEU system should be able to access a geo-location database to retrieve spectrum availability information (TVWS pool). Simulations can be used to generate the data to populate the database. The COGEU geo-location database and interfaces are specified in Chapter 3 of this deliverable.
2.2.2.1 Victim link

Technical parameters of the DVB-T broadcasting tower are described in Table 4. The transmitter antenna pattern is assumed to be omnidirectional in azimuth and elevation.

Table 5 DVB-T Transmitter technical parameters, from [5]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>658</td>
<td>MHz</td>
</tr>
<tr>
<td>Power</td>
<td>79.15</td>
<td>dBm</td>
</tr>
<tr>
<td>Antenna height</td>
<td>200</td>
<td>m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>Omnidirectional</td>
<td></td>
</tr>
<tr>
<td>Antenna peak gain</td>
<td>0</td>
<td>dBi</td>
</tr>
</tbody>
</table>

For a DVB-T home receiver, the technical parameters are described in Table 5.

Table 6 DVB-T receiver technical parameters, from [5] and [6]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna height</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>Yagi</td>
<td></td>
</tr>
<tr>
<td>Antenna peak gain</td>
<td>9.15</td>
<td>dBi</td>
</tr>
<tr>
<td>Noise floor</td>
<td>-98.17</td>
<td>dBm</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>-77.17</td>
<td>dBm</td>
</tr>
<tr>
<td>Reception Bandwidth</td>
<td>7.610</td>
<td>MHz</td>
</tr>
<tr>
<td>Blocking response</td>
<td>Protection Ratio function</td>
<td></td>
</tr>
</tbody>
</table>

The DVB-T receiver antenna pattern is based on ITU-R BT.419-3 recommendation. The Antenna pattern is illustrated in Figure 11.

![Antenna horizontal pattern of a DVB-T receiver](image)

Figure 11 Antenna horizontal pattern of a DVB-T receiver

The protection ratio functions of the victim receiver are extracted from [7], where protection ratio measurements for cognitive radio systems using LTE technology against DVB-T reception were conducted. Results are depicted in Figure 12 as they are used in SEAMCAT, i.e. the ratio of maximum acceptable level of interfering signal to the wanted signal level, at a given frequency separation. Note that this representation is inverted when compared with the definition of protection ratios presented in deliverable D3.1.
Figure 12 Protection Ratio function of a DVB-T receiver against a) LTE BS and b) LTE UE.

2.2.2.2 Interfering link

Table 6 shows technical parameters used to simulate an LTE BS and LTE UE with SEAMCAT [7].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Base Station Value</th>
<th>Base Station Units</th>
<th>User Equipment Value</th>
<th>User Equipment Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>658</td>
<td>MHz</td>
<td>658</td>
<td>MHz</td>
</tr>
<tr>
<td>Power</td>
<td>56</td>
<td>dBm</td>
<td>23</td>
<td>dBm</td>
</tr>
<tr>
<td>Antenna height</td>
<td>10</td>
<td>m</td>
<td>1.5</td>
<td>m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>Directional 120°</td>
<td></td>
<td>Omnidirectional</td>
<td></td>
</tr>
<tr>
<td>Antenna peak gain</td>
<td>0</td>
<td>dBi</td>
<td>0</td>
<td>dBi</td>
</tr>
</tbody>
</table>

Spectral emission mask for LTE BS and UE are taken from document [7]: For LTE UE, the emission mask is based on the standard 3GPP TS 36.101 V9.20 [20] that defines the maximum OoB (Out-of-Band) emission limits for user equipment (UE). For LTE base stations (BS), the spectrum mask suggested by CEPT in Report 30 [21] is considered. Reference bandwidth in Figure 13 a) and b) is 30 kHz.

The LTE UE antenna pattern is assumed to be omnidirectional in azimuth and elevation. For LTE BS, a tri-sectored antenna pattern is considered. Figure 14 shows the horizontal and vertical pattern for one sector.
2.2.2.3 Propagation models

Simulations are performed (at 658 MHz) with propagation model ITU-R P.1546 for the DVB-T (victim) link.

Table 8 Parameters used for ITU-R P.1546 propagation model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General environment</td>
<td>Rural</td>
<td></td>
</tr>
<tr>
<td>System Type</td>
<td>Digital</td>
<td></td>
</tr>
<tr>
<td>System bandwidth</td>
<td>&gt;1</td>
<td>MHz</td>
</tr>
<tr>
<td>Time Percentage</td>
<td>50</td>
<td>%</td>
</tr>
</tbody>
</table>

Extended Hata model available in SEAMCAT is used to simulate the propagation of interfering signals between the DVB-T receiver and the LTE interferer. Environment is set above rooftop for LTE BS and below rooftop for LTE UE.

Table 9 Parameters used for Extended Hata propagation model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>General environment</td>
<td>Rural</td>
</tr>
<tr>
<td>Local environment (receiver)</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Local environment (transmitter)</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Propagation environment</td>
<td>Above/below Roof</td>
</tr>
</tbody>
</table>

2.2.2.4 Interference criterion

The criterion for interference to occur is for the digital TV receiver to have a carrier to noise ratio (C/N) less than the minimum allowable value. Using a C/N value equal to 21 dB [5] and considering that desensitization due to noise, (N+I)/N, is equal to 0.5 dB, then

\[
\frac{I}{N} = 1 - \left( \frac{N + I}{N} \right) = 1 - 10^{0.5/10} = 0.122 \quad \Rightarrow \quad \frac{I}{N_{dB}} = -9.136 \text{ dB}
\]

The following ratios can now be obtained,

\[
C_{dB} = C/N_{dB} - I/N_{dB} = 21 - (-9.136) = 30.136 \text{ dB}
\]

and

\[
C/N_{dB} = C/N_{dB} - (N + I)/N_{dB} = 30.136 - 0.5 - 9.136 = 20.5 \text{ dB}
\]

The ratios C/I, C/(N+I), (N+I)/N and I/N are set in SEAMCAT and defines the interference criteria of the simulation scenario.
2.2.2.5 Simulation scenarios
Figure 15 illustrates the interfering and the DVB-T deployment geometries considered in this study. The interfering network is modelled as a single link between a Base Station (BS) and User Equipment (UE). The 3GPP Long Term Evolution (LTE) standard (based on a 5 MHz channel bandwidth) is used as a proxy for the interfering link technology in this study. The impact of the co-channel interference caused by LTE uplink or downlink is evaluated for the case of a victim DVB-T receiver.

![Figure 15 Interference scenario (from [17])]()

The area surrounding the interference scenario is subdivided into pixels, using a grid with rectangular coordinates (x,y), with 1 km resolution. So, each pixel is a square with dimension 1km × 1km. The origin (0,0) is the DVB-T receiver position. The interfering transmitter is then placed in the center of each pixel, and a simulation is run, sweeping the interfering power signal to find the maximum EIRP admissible for 1% and 10% probability of interference. The results are saved and produce a map with the maximum allowable power that can be used by a LTE over TVWS secondary transmitter. The simulation assumes that the interfering transmitter is not allowed to transmit inside the coverage area of the DVB-T transmitter.

This power map delivers spatial information on maximum allowed transmit power level (EIRP<sub>max</sub>) that can be used by secondary spectrum users (white spaces devices) and can be an input to a geo-location database. Results of simulation are described in the following section.

2.2.2.6 Results and analysis
For a worst-case scenario situation, the DVB-T receiver must be located at the edge of the cell coverage, where mean received power is -68 dBm (56.21 dBμV/m @ 10m) [5]. From the parameters defined for the victim link, this corresponds to a distance between DVB-T transmitter and receiver of 52.9 km.

Plots of maximum allowable LTE BS interferer transmit power (EIRP) levels computed using the above-described techniques are shown in Figure 16. Probability of interference was set at 1% and 10%. The plots assume that a 56 dBm maximum EIRP level is allowed. The two plots cover roughly an area with 250 km x 400 km.

![Figure 16 EIRP<sub>max</sub> [dBm] allowed for LTE BS for: a) 1% and b) 10% probability of interference with DVB-T Rx](image)
The dark blue colour indicates the protected contour areas of DVB-T receivers, where secondary users operation on that frequency would not be possible. The shapes of the contours are directly related to the receiver antenna pattern. The dark red color indicates areas where WSD operation is possible at full power (56 dBm) levels.

The same procedure was used considering that the interferer is now the LTE UE, with maximum allowed EIRP level of 23 dBm. Figure 17 shows the plots produced.

![Figure 17: EIRP max [dBm] allowed for LTE UE for 1% a) and 10% b) probability of interference with DVB-T Rx](image)

For both scenarios of interference, the results show that the protection contour around the primary receiver increases as the probability of interference is set to lower values. Moreover, due to the fact that LTE BS are in line-of-sight with the DVB-T aerial antenna, is the LTE downlink that limits the white space area.

Table 9 presents the calculated radius of the area around the DVB-T receiver for all four case studied, where WSD power levels should be less than or equal to 0 dBm. This area could be considered as a protected area by the geo-location Database.

<table>
<thead>
<tr>
<th>Type of Interferer</th>
<th>LTE BS</th>
<th>LTE UE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1% Interference</td>
<td>16 km</td>
<td>4.5 km</td>
</tr>
<tr>
<td>10% Interference</td>
<td>7 km</td>
<td>2.5 km</td>
</tr>
</tbody>
</table>

2.2.3- Computation of TVWS maps considering autonomous sensing

In this section, SEAMCAT is used to compute TVWS maps considering that the WSD depends only on local sensing to detect opportunities in TV bands (without location information and database access). SEAMCAT recently included cognitive features able to sense primary signals [17]. Spectrum sensing essentially involves conducting a measurement within a candidate channel to determine whether any protected service is present before transmitting. When a channel is determined to be vacant, sensing is typically applied to adjacent channels to identify what constraints there might be on transmission power, if any.

A key parameter for spectrum sensing is the detection threshold that is used by a cognitive device to detect the presence/absence of a protected service's transmission. The value set by OFCOM-UK is -120 dBm, as described in deliverable D2.1. If the cognitive device detects no emission above this threshold in a specific channel, the WSD is allowed to transmit; otherwise the WSD keeps silent or look into other channels.

After selection of the frequency range for the DVB-T system, the algorithm implemented in SEAMCAT automatically computes the possible DVB-T channels where a WSD can operate. The WSD select an appropriate operating frequency and controls its emission power based on EIRP max in block limit [9], according to the levels from Figure 18. Co-channel interference is not allowed in this scenario, since EIRP max is set to -1000 dBm (not visible in this figure).
The simulation scenario follows the same geometry presented in section 2.2.2, but now there is an additional sensing signal (sRSS) from the DVB-T transmitter received by the cognitive transmitter device.

2.2.3.1 Victim link
The primary system is the same as in section 2.2.2.1. Only the spectral emission mask of the DVB-T transmitter needs to be additionally defined. The following spectrum mask (Figure 20) is adopted for DVB-T [8] and used in the simulations.

---

**Figure 18** EIRP<sub>max</sub> in-block limit defined in spectrum sensing options.

**Figure 19** Scenario geometry and signals for autonomous sensing (from [17])

**Figure 20** Spectral emission mask for DVB-T transmitter, Measurement bandwidth: 4 kHz
### 2.2.3.2 Interfering link

The LTE BS and UE have the same characteristics as in the previous section, but additional sensing parameters from Table 10 have to be defined.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unwanted emission floor [9]</td>
<td>-63.8</td>
<td>dBm</td>
</tr>
<tr>
<td>Detection threshold (OFCOM UK proposal) [10]</td>
<td>-120</td>
<td>dBm</td>
</tr>
<tr>
<td>Probability of failure</td>
<td>0</td>
<td>%</td>
</tr>
<tr>
<td>Sensing bandwidth</td>
<td>8</td>
<td>MHz</td>
</tr>
<tr>
<td>Hidden Node Margin (DVB-T -&gt; LTE BS) [11]</td>
<td>0</td>
<td>dB</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>645 - 669</td>
<td>MHz</td>
</tr>
</tbody>
</table>

The frequency range corresponds to 3 consecutive adjacent channels; each with a bandwidth of 8 MHz. This range is chosen according to COGEU system requirements (frequency of operation between 622-790 MHz) [18]. The Hidden Node Margin (HNM) is zero when the interferer is the LTE BS (downlink), since both victim and interferer are above roof top level, and it is assumed that there is no obstruction between them. The HNM is increased to 35 dB when the cognitive LTE mobile device is the interferer (uplink), since DVB-T receiver antenna is usually not visible from the level where the device is located, typically 1.5 m above ground. This value of HNM includes 99% of locations in any environment [19].

### 2.2.3.3 Results and analysis

Following simulation results are presented to illustrate the EIRPmax that the WSD is allowed to transmit when spectrum sensing is used. The represented power is an average of the EIRP obtained from the 3 channels defined in the simulation setup. For sake of simplicity, simulations are made only in one dimension, moving the interferer from the DVB-T receiver along a line, starting at point (1 km, 0) and ending at point (200 km, 0). As a reference for comparison, the same plot is made using the geo-location database approach, with WSD EIRPmax for 1% probability of interference (see section 2.2.2.6).

Figure 21 shows the results when LTE UE is the interferer. Results show that autonomous sensing is generally more limiting than database approach. Autonomous sensing artificially limits the maximum transmit power allowed for WSD operation due to the high hidden node margin used to protect the primary users. For lower separation distances, the allowed emission power is too low to be considered useful for a communication system. The discontinuity in the autonomous sensing plot is due to the EIRP\(_{\text{max}}\) in-block limit function used in the simulation to control the emitted power from the WSD (depicted Figure 18).
The same method is conducted with a LTE BS interferer and the results are presented in Figure 22. With HNM now set to 0 dB, the two graphs are showing similar trend for distance above 10 km. Once again, the influence of the EIRP\textsubscript{max} in-block limit function is clearly visible in the autonomous sensing approach, with an increase power step at approximately 50 km. however, geo-location database approach result again in higher values of EIRP for the interfering transmitter.

![Figure 22 EIRP\textsubscript{max} for LTE BS](image)

**2.2.4- Impact of wireless microphones activity in TVWS availability**

PMSE systems have already been using the frequency band 470-790 MHz on a secondary basis for some decades. As already described in D2.1 (section 5.6) [19], there are different usage modes. PMSE could be used indoor and outdoor, with fixed or mobile equipment. Several scenarios with different characteristics must be simulated in order to get acceptable results from interference simulations.

As stated on COGEU system requirements (D3.1), autonomous sensing is mandatory for PMSE because some users are not registered in the geo-location database. From D2.1, Table 2 gives an overview of applications for PMSE. One of the most demanding PMSE systems in terms of QoS and bandwidth are Professional Wireless Microphone Systems (PWMS). PWMS need to provide a high audio quality with 100 % duty cycle. The expected audio quality needs to be completely reliable. This section analyses the interference between a secondary system, LTE over TVWS, and a PWMS link.

**2.2.4.1 Victim link**

The PWMS is the victim link. The details for modelling of the PWMS receiver (victim) are displayed in Table 11 and follow the guidelines from [12]. The receiver antenna pattern is assumed to be omnidirectional in azimuth and elevation.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>-110</td>
<td>dBm</td>
</tr>
<tr>
<td>RF squelch (typical)</td>
<td>-95</td>
<td>dBm</td>
</tr>
<tr>
<td>Noise floor</td>
<td>-115</td>
<td>dBm</td>
</tr>
<tr>
<td>C/I</td>
<td>20</td>
<td>dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>200</td>
<td>kHz</td>
</tr>
<tr>
<td>Antenna height</td>
<td>1-10</td>
<td>m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>Omnidirectional</td>
<td></td>
</tr>
<tr>
<td>Antenna gain</td>
<td>2.15</td>
<td>dBi</td>
</tr>
</tbody>
</table>

The maximum co-channel interference permitted from WSD should be below -115 dBm at the PWMS receiver, taking as a basis analogue FM PWMS systems [13]. Figure 23
represents the absolute power level (in dBm) of maximum interfering signal, which might be tolerated by the receiver at a given frequency separation.

![Graph showing maximum interference level for a 200 kHz channel PWMS receiver.](image)

Figure 23 Maximum interference level for a 200 kHz channel PWMS receiver.

Technical parameters for PWMS transmitter simulation are summarized in Table 12 and extracted from [12].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF bandwidth</td>
<td>200</td>
<td>kHz</td>
</tr>
<tr>
<td>Antenna height (mobile system)</td>
<td>1.5</td>
<td>m</td>
</tr>
<tr>
<td>Antenna height (fixed system)</td>
<td>1-10</td>
<td>m</td>
</tr>
<tr>
<td>Antenna type</td>
<td>Omnidirectional</td>
<td></td>
</tr>
<tr>
<td>Antenna gain</td>
<td>0</td>
<td>dBi</td>
</tr>
<tr>
<td>Output power (hand-held devices)</td>
<td>0-17</td>
<td>dBm</td>
</tr>
</tbody>
</table>

Handheld equipment are equipped usually with a $\frac{\lambda}{4}$ or $\frac{\lambda}{2}$ dipole. Radiation pattern is assumed to be omnidirectional in azimuth but not in elevation. Figure 24 shows the vertical pattern in polar coordinates.

![Diagram showing vertical pattern for wireless microphone transmitter antenna.](image)

Figure 24 Vertical pattern for wireless microphone transmitter antenna.

The following figure provides spectrum mask for PWMS systems [14].
Figure 25 Spectrum emission mask (Measurement bandwidth: 200 kHz).

Fading Margin up to 25 dB (measured value) is commonly used for link budgets with Rayleigh fading distribution. Body loss of between 10 dB and 30 dB is generally used for link budgets. Several references show that the building penetration loss varies significantly with different wall materials. Therefore calculations, which include building penetration loss, should be performed for minimum and maximum wall attenuation, ranging from 5.5 dB to 20 dB. These values typically cover 99% of all possibilities [12].

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fading margin</td>
<td>&lt;= 25</td>
<td>dB</td>
</tr>
<tr>
<td>Body absorption</td>
<td>10 - 30</td>
<td>dB</td>
</tr>
<tr>
<td>Distance from Tx to Rx antenna</td>
<td>20 - 100</td>
<td>m</td>
</tr>
<tr>
<td>Wall attenuation</td>
<td>5.5 - 20</td>
<td>dB</td>
</tr>
</tbody>
</table>

### 2.2.4.2 Interference criterion

The criterion for interference to occur is for the PWMS receiver to have a carrier to interference ratio (C/I) less than the minimum allowable. Using the values from Table 11, considering that the minimum required signal level for high quality audio is typically -100 dBm (5 dB below squelch threshold) with a C/I requirement of 20 dB for current analogue FM equipment (200 kHz bandwidth) [12], we have

\[
\text{Sensitivity} = \text{Noise Floor} + \frac{C_i}{(N+I)_{\text{dB}}}
\]

\[
\frac{C_i}{(N+I)_{\text{dB}}} = -100 + 115 = 15 \text{ dB}
\]

The following ratios can now be obtained,

\[
\frac{I}{(N+I)_{\text{dB}}} = \frac{C_i}{(N+I)_{\text{dB}}} - \frac{C_i}{N_{\text{dB}}} = 6 \text{ dB}
\]

\[
\frac{I}{N_{\text{dB}}} = -10 \log \left( \frac{(N+I)}{I} - 1 \right) = 10 \log (2.98) = -5 \text{ dB}
\]

\[
\frac{C_i}{N_{\text{dB}}} = \frac{C_i}{I_{\text{dB}}} + I/N_{\text{dB}} = 21 - 5 = 16 \text{ dB}
\]

\[
\frac{(N+I)}{N_{\text{dB}}} = \frac{C_i}{N_{\text{dB}}} - \frac{C_i}{(N+I)_{\text{dB}}} = 16 - 15 = 1 \text{ dB}
\]

From the above calculations, a desensitization of 1 dB also means that interference from WSD must stay below noise level by a factor equal to I/N, which results in I = -121 dBm. The ratios C/I, C/(N+I), (N+I)/N and I/N are used by SEAMCAT as interference criteria to protect PWMS. These parameter will be used as the main criterion for simulation analysis in section 2.2.4.5.
2.2.4.3 Propagation model

Wireless microphone signals almost never operate under free space conditions. Therefore, in addition to the free space path loss, signals are subject to additional attenuation due to multipath fading, shadowing, absorption and scattering.

Due to the above factors, propagation losses are normally predicted statistically based on a large number of measurements in the environment where the system is expected to operate. SEAMCAT has built-in propagation models available, which are extension to the Hata and Okumura propagation models. The model use in this study is the called Extended Hata and Extended Hata (SRD). Table 14 summarizes their validity conditions [15].

Table 15 Validity ranges for Extended Hata models

<table>
<thead>
<tr>
<th>Propagation Model</th>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Hata (SRD)</td>
<td>Mobile and base station height (below roof top)</td>
<td>1-3</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td>Distance</td>
<td>&lt;= 300</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td>Direct-Line-Of-Sight or near-direct-LOS</td>
<td></td>
</tr>
</tbody>
</table>

2.2.4.4 Simulation scenario description

There is no 'one single scenario' which describe the usage of wireless microphone systems. Therefore compatibility / sharing studies need to be performed with different possible scenarios. These different scenarios need to be reflected also in the sensing and geo-location system requirements adopted by COGEU.

The propagation models available in SEAMCAT limit the simulation scenarios that can be studied. As an example, we use Extended Hata (SRD) model for interference analysis between wireless microphones and mobile interferer, with near-direct-LOS. The heights of all devices are set to 1.5 m and maximum distance between any device is 300 m. More details on the model parameters are in Table 15.

Table 16 Parameters used for Extended Hata – SRD propagation model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>General environment</td>
<td>Urban</td>
<td></td>
</tr>
<tr>
<td>Local environment (receiver)</td>
<td>Both indoor</td>
<td></td>
</tr>
<tr>
<td>Propagation environment</td>
<td>Below Roof</td>
<td></td>
</tr>
<tr>
<td>Wall Loss (indoor indoor)</td>
<td>5.0</td>
<td>dB</td>
</tr>
<tr>
<td>Wall Loss std. dev. (indoor indoor)</td>
<td>10.0</td>
<td>dB</td>
</tr>
<tr>
<td>Size of the Room</td>
<td>4.0</td>
<td>m</td>
</tr>
<tr>
<td>Height of each floor</td>
<td>3.0</td>
<td>m</td>
</tr>
</tbody>
</table>

The simulated scenario is depicted in Figure 26. The receiver is located between the wireless microphone and the cognitive mobile device. General environment is set to urban, and local environment as indoor.

Figure 26 Simulation scenario

Depending on the relative location of the pair of transmitter and receiver, Extended Hata (SRD) model uses a statistical estimation of whether the transmitter and the receiver are in the same room, using a probability P, depending on a separation distance d.
Table 17 Calculation scheme to estimate the relative location between transmitter and receiver

<table>
<thead>
<tr>
<th>Distance Range</th>
<th>Same building Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d \leq 0.02$ km</td>
<td>$P = 1$</td>
</tr>
<tr>
<td>$0.02 \text{ km} &lt; d \leq 0.05$ km</td>
<td>$P = (0.05 - d)/0.03$</td>
</tr>
<tr>
<td>$0.05 \text{ km} &lt; d$</td>
<td>$P = 0$</td>
</tr>
</tbody>
</table>

The victim link is defined in such a way that a PWMS Rx is at the edge of the coverage area with received signal equal to -95 dBm. With 10 dBm power emitted from the wireless microphone and using Extended Hata (SRD) propagation model, this corresponds to 100 m separation distance from the PWMS transmitter. Remaining parameters are defined according to section 2.2.4.1.

The interfering link for this particular scenario is a LTE UE over TVWS operating in uplink. The interferer is located inside or outside the same room as the victim link, depending on the distance. The propagation model used imposes limits to the separation distance between PMSE receiver and interferer (300 m maximum).

2.2.4.5 Results and analysis

Co-channel interference is the first situation analyzed. Using the frequency 654 MHz for both systems, and for two different distances between LTE UE and PWMS receiver. Figure 27 shows the interfering Received Signal Strength (iRSS) as a function of the EIRP transmitted by the WSD (LTE UE).

![Figure 27 Co-channel power interference as a function of distance.](image)

The simulation result shows that in order to maintain the interferer power below -121 dBm, demanded by PWMS protection, the LTE UE cannot emit above 2 dBm for a separation distance of 300 m. If the distance is decreased to 100 m, the emitted power of LTE UE cannot exceed -16 dBm (too low for any practical application).

Other simulations were carried out to identify the necessary channel separation between primary and secondary systems, in order to maintain interference power originated by the secondary transmitter (LTE UE) below -121 dBm. Figure 28 shows the adjacent-channel interference as a function distance for 1, 2 and 3 channels separation.
Figure 29 Adjacent-channel interference as a function distance.

The horizontal red dotted line in Figure 29 shows the maximum power level from the cognitive interferer (-121 dBm) for 1 dB desensitization. The results shows that with one channel separation (8 MHz), an LTE UE can transmit 22 dBm located at 300 m distance from a PMSE receiver without harmful interference. The safety distance can be decreased to 145 m if 2 channels separation is used. No further improvements are visible by increasing the channel separation above 16 MHz.

2.2.5- COGEU proposal for the development of SEAMCAT

SEAMCAT is a tool developed by CEPT that doesn’t allows the automatic computation of TVWS maps. In fact, the computations of TVWS maps with SEAMCAT, using the process described in section 2.2.2.5, is a time consuming process. This section describes several techniques used.

Considering a geo-location database approach, the interfering transmitter is placed in specific locations around the DVB-T receiver, according to the spatial grid resolution and size. For each position, the EIRP of the interferer is swept from a minimum to a maximum value. Using Monte-Carlo analysis, SEAMCAT produces the wanted signal and interfering signals arriving at the DVB-T receiver for all the EIRP power defined, and the resulting vector signals (dRSS and iRSS) are stored. MATLAB is used to compute the probability of interference from these vectors and sets the maximum EIRP that an interferer can use to produce interference below a certain percentage.

For the autonomous sensing approach, the new cognitive features of SEAMCAT already produces a maximum EIRP that can be used by the interferer. However, the interferer needs to be placed around the DVB-T receivers, like in the geo-location approach, to get a TVWS map.

Whatever the approach used, TVWS map produced with SEAMCAT implies the execution of many repetitive tasks, changing always the same set of parameters, i.e.:

- The relative x and y location between DVB-T receiver and LTE transmitter: SEAMCAT already offers batch simulation to process several scenarios at once. However, all scenarios need to be defined one by one by the user for every (x,y) position.

- The maximum power transmitted by the WSD transmitter: When the “translation mode” is chosen in SEAMCAT, the user may calculate the probability of interference as function of the output power of an interfering transmitter, but the result in only displayed as a chart and cannot be saved as a data file (this drawback will be solved in forthcoming versions).

Moreover, repetitive tasks may be accomplished automatically using appropriate software tools. Automator [22] and Automise [23] were tested together with MATLAB to compute TVWS maps from
iRSS and dRSS data vectors. With little programming, these solutions effectively diminish the time need to produce TVWS maps.

SEAMCAT Technical Group (STG) analyses new features and enhancements from users contributions periodically. These actions are done creating tickets through SEAMCAT Bug Tracking Tool. COGEU has been active in this task, reporting software bugs (ticket #458) and sending proposals to enhance existent features and proposing new ones (ticket #475) (ticket #517). Two enhancements proposed by COGEU were approved by CEPT and will be available in the next official release of SEAMCAT.
2.3- Spectrum occupancy measurements in TV bands

Spectrum occupancy measurement campaigns in TV bands were carried out by IRT in the southern part of Germany (Bavaria), in urban, suburban and rural areas, within and around Munich. The spectrum occupancy data recorded will be later on combined with simulation studies to generate the TV white spaces maps in Munich area under COGEU T6.5.1- “Available TVWS identification”. In addition measurements were carried out in Portugal (Castelo Branco city) to analyze the impact of mobility and cooperation on sensing performance.

2.3.1- Lab tests with the measurement set up

The DVB-T signal power, received at the height of 1.5 m and 10 m, in the UHF-frequency channels 21 to 69, using a vertically-polarized (VP) omnidirectional antenna, was measured, recorded and evaluated statistically. The antenna used for reception consisted of a Schwarzbeck broadband balun/holder UBAA 9114 with biconical element BBVU 9135 [24].

![Figure 30 Polarized broadband antenna for measurements](image)

The power was measured in the 8 MHz bandwidth of the DVB-T channel using a Rohde&Schwarz ETL TV Analyzer. The ETL can read the DVB-T signal cell ID even at very low power levels, permitting to find the origin of the DVB-T signal.

![Figure 31 Rohde&Schwarz ETL TV Analyzer](image)

The power values given in this report are corrected for the antenna to ETL cable attenuation and represent the power at the antenna output. Using the antenna factor the field strength can be calculated.

The ETL Test Receiver measures the signal quality of a wide variety of TV-related signals, analogue or digital. In the context of the COGEU project, a version with a DVB-T test receiver and a spectrum analyser in the same instrument is used to establish a first evaluation of the sensitivity of such a test receiver.

2.3.1.1 Cell ID detection mechanism

In a DVB-T signal, the Transmission Parameter Signalling (TPS) transports information about the DVB-T signal itself in such a way that a receiver can easily decode this information and synchronise to the correct mode more rapidly. For this purpose, a certain number of the OFDM carriers in each symbol (17 TPS carriers for the 2K mode and on 68 carriers for the 8K) are modulated differentially
with the same information bit, i.e. this information bit is carried by all TPS carriers of one OFDM symbol.
The TPS carriers convey information on modulation parameters, the guard interval length, code rates, the transmission mode, the frame number and the cell identification. Independent of the constellation of the OFDM carriers transporting the payload DVB-T signal, the TPS carriers are DBPSK modulated (Differential Binary Phase Shift Keying). This very robust modulation, and the transport of the same information bit on all TPS carriers of each OFDM symbol, allow a DVB-T receiver to pick up the TPS information under extremely adverse circumstances where a synchronisation to the complete DVB-T signal is not possible anymore.

The Cell Identifier is a digital number that provides an identification of individual transmitters in a network. This Cell_ID is decoded and displayed by the ETL Test Receiver, and is used for the evaluation of the sensing threshold of the instrument.

For the first tests, the signal generator (Type SFU) was set to the DVB-T mode that is currently used in Germany: 8K FFT, 16 QAM, GI 1/4, CR 2/3. Channel 49 with the centre frequency of 698 MHz was used. To prevent the ETL Test Receiver from waiting for synchronisation of the DVB-T signal, the instrument setting 'FEC SYNC NOT REQUIRED' was chosen.

For the evaluation tests, the Cell_ID was set to '3456' at the signal generator. The power level of the DVB signal at the output of the signal generator was then reduced in steps below the noise floor of the ETL Test Receiver. This procedure is equivalent to the usage of an AWGN channel.

In Figure 32 above, the level of the DVB-T signal is -103 dBm. The ETL Test Receiver shows a level of -95.5 dBm. This is the result of the combined signal which consists mainly of noise but also shows the underlying DVB-T signal. This is illustrated at a higher signal level (DVB-T signal at -60 dBm) where AWGN can be added (Figure 33). The DVB-T signal is shown in blue, the noise floor in green and the combined signal in yellow. The span is 20 MHz, the scale is 1 dB/ div. The DVB-T signal causes an increase of the measured level of about 1 dB.
In conclusion, this means that the DVB-T signal is detectable down to 6 dB below the noise floor. This is the limit where the Cell_ID can still be correctly decoded for more than 50% of the time. The value is available after several seconds. For a few percent of the cases, the Cell_ID is decoded incorrectly at this level. An example is given in Figure 34.

For a certain percent of the measurements, the Cell_ID is not decoded at all at this level. Therefore, a careful evaluation of the measurements over a certain period of time is required.
For different types of channels, e.g. a Gaussian, Ricean or Rayleigh channel, the DVB-T signals require different C/N ratios for decodability. The DVB-T standard provides simulation results for the C/N required for a quasi-error-free (QEF) data stream from the demodulator. QEF corresponds to a BER before Reed-Solomon of $2 \times 10^{-4}$. Measurements confirm that the C/N margin that needs to be added when applying the standard stationary Rayleigh profile with 20 paths, is around 4 dB. For a TU6 profile at 50 km/h it is around 6 to 7 dB.

Figure 36 DVB-T signal of -103 dBm with TU6/50 profile

The Cell ID detection mechanism does not show any such dependency on the propagation profile. Even for the TU6/50 profile, it operates down to the same level of C/N = -6 dB. Figure 36 shows such a DVB-T signal averaged over 100 sweeps. The same holds for the Rayleigh20 and the Pedestrian Outdoor 3 km/h (PO3) profiles.

Figure 37 DVB-T signal of -103 dBm with PO3 profile

To evaluate the behaviour of a DVB-T receiver in the presence of a strong narrow-band interferer, the DVB-T signal was combined with a CW signal which was set 30 dB below the DVB-T signal (on a spectrum analyser screen it would therefore appear at almost the same level if the Resolution Bandwidth is set to 10 kHz).
Figure 38 and Figure 39 show the constellation diagram and the table of measurement results for the unimpaired DVB-T signal.

The impact of the CW interferer can be illustrated by measuring and displaying the Modulation Error Ratio (MER) for the OFDM carriers in the vicinity of the interferer. In Figure 40, the interferer is set 1.5 MHz above the centre frequency of the DVB-T signal. It therefore impacts on the OFDM carrier around carrier number 4750. The screen shot shows the degradation of the MER value for the OFDM carriers in this part of the signal; 200 carriers from 4650 to 4850 are evaluated for this measurement.
The CW interferer can also be traced through the constellation diagram (Figure 41), although here the nature of the interference is not obvious.

The QoS parameters (Figure 42) show the degradation in the parameters MER (peak) and EVM (peak), where the worst values (per OFDM carrier) are given, but not in the corresponding rms values (over all OFDM carriers). As a result, the quality of the DVB-T signal is still very good (very low BER before RS).
2.3.1.2 Measurements with location information

Mobility changes the propagation channel between the DVB-T transmitters and the secondary terminal’s antenna. COGEU use cases consider mobility of the secondary spectrum user, therefore the impact of mobility on sensing is an important issue. In order to investigate the impact of mobility, the R&S DVB-T test receiver ETL can be connected to an external GPS device via USB. If active, the connected external GPS device is enabled and the current position is recorded in the measurement log. The following parameters are recorded:

- Longitude of the current position of the test receiver. The value is shown in degrees (separated by commas).
- Latitude of the current position of the test receiver. The value is shown in degrees (separated by commas).
- Altitude of the current position of the test receiver. The value is shown in Meter (separated by commas).
- HDOP (horizontal dilution of precision) This value is an indication of the precision of the GPS position. Values < 4 indicate excellent reception conditions for the satellite signals.
- Satellites: This value indicates the number of currently received satellites which allows conclusions on the accuracy of the measured values.

Apart from the last parameter (number of satellites received), all parameters are only shown if the current position is available from the GPS device.

A test drive in the Munich area showed that a full set of measurement values is available from the DVB-T test receiver every 10 m when driving with approximately 50 km/h. The measurement values include all the QoS parameter as normally displayed on the instrument’s screen (see for example Figure 40). In addition, the geo-location data from the GPS device are also recorded. The data are stored on the test receiver as a .csv file. Figure 43 shows an example of such a file.
For a quick overview of the conditions in the coverage area, a visualisation tool is being developed that allows for a colour coding of user defined thresholds of the parameter ‘Level (average)’ and for the display of coloured dots on a suitable map. The example in Figure 44 shows a zoom-in on the measurement points about 10 m apart from each other.

This tool is still under development at R&S and will be used to analyze the effect of mobility on the performance of sensing mechanisms of DVB-T signals. Test drives in different scenarios and at different speeds will be carried out and results will be reported in D4.2.

![Figure 44 Visualisation of the measurement parameter 'Level (average) on the map](image)

### 2.3.1.3 Example of spectrum measurement in R&S premises in Munich

In order to get a first indication of spectrum occupancy in Munich area, spectrum measurements in TV bands were carried out in R&S premises using the ETL Test Receiver. The antenna height was 15 m above ground level, and the antenna was a directional antenna with a gain of approximately 8 dB pointing to the local transmitter site in the north of Munich.

![Figure 45 Example for spectrum occupation in the Munich area](image)
The following channels are transmitted from the same site (Olympic tower in the north of Munich):

- ch 34 578 MHz
- ch 35 586 MHz
- ch 48 690 MHz
- ch 54 738 MHz
- ch 56 754 MHz
- ch 66 834 MHz

Also visible on the spectrum analyser, although only received through the antenna side lobes and partly below the threshold set here to -104 dBm, are:

- ch 25 506 MHz  Tx station approx. 50 km away
- ch 29 538 MHz  Austrian channel
- ch 32 562 MHz  Austrian channel

In addition, several low-level interference signals are pictured which originate from the R&D labs on the premises.

Section 2.3 will present an extensive spectrum measurement campaign in urban, suburban and rural areas, within and around Munich.

2.3.1.4 Measurements of wireless microphones signals

This section provides lab measurements focused on the establishing of currently available sensing techniques for PMSE signals and the definition of appropriate threshold for which sensing tools can be operated. For the tests of sensing PMSE signals, a R&S Signal Generator produced a FM signal with 100 kHz deviation, preemphasis of 50 µs and audio frequency of AF=1 kHz. The FM test signal is shown in Figure 46.

Using the spectrum analyser part of the ETL Test Receiver, the FM signal was reduced to a level of -110 dBm. At this level, the FM signal is still clearly identifiable above the noise floor (Figure 46). To obtain this indication, it is necessary to use a sweep time around 1 second over a DVB-T channel of 8 MHz, and to average over about 10 traces. Therefore, the result becomes available after approximately 10 seconds. The threshold level of -110 dBm provides a benchmark of the performance of the currently available PMSE sensing tools against which any COGEU improvement can be measured.
Since the PMSE signals do not carry a specific identification (as in the case of the DVB-T signal), their identification cannot rely on auto-correlation or similar properties, and power sensing seems the most promising option.

To estimate how different propagation profiles influence the detectability of the simulated PMSE signal, its level was set to -60 dBm and AWGN was added with C/N = -15 dB. In Figure 47 the yellow trace shows the simulated PMSE signal without noise, the other traces show the same signal with AWGN added for different propagation profiles:

- Green: AWGN
- Blue: TU6 50 km/h
- Purple: PO3
- Dark blue: Rayleigh RL20

The measurement shows clearly, that averaging over several sweeps eliminates the impact of the different propagation profile almost completely.

COGEU sensing algorithms for DVB-T and PMSE will be developed in T4.3 and reported in D4.2.

---

Figure 47 Influence of propagation profiles on PMSE detection
2.3.2 Spectrum measurements campaign in Munich area

The COGEU system will be demonstrated in Munich area, therefore extensive spectrum occupancy measurement campaigns in TV bands were carried out by IRT in the southern part of Germany (Bavaria), in urban, suburban and rural areas, within and around Munich. The DVB-T transmitters in Bavaria region are shown in the following map.

![DVB-T transmitters in Bavaria](image)

Figure 48 DVB-T transmitters in Bavaria (graphic from BLM).

Seven sites were chosen for the measurements campaign:

- **Urban regions**: Munich-Schwabing, Munich Neuperlach
- **Suburban regions**: Munich-Freimann, Munich Obermenzing, Ebersberg, Freising
- **Rural regions**: Eurasburg

On every site 20 measurements points were chosen, and at every measurement point a channel power scan was carried through with the antenna at a height of 10 m and at a height of 1.5 m.

The following map shows the 7 locations where the spectrum occupation were measured. The picture covers an area of 70 km x 50 km.
For every TV-channel, the median value and the standard deviation of the power value distribution was calculated.
2.3.2.1 Measurement results in urban areas of Munich

2.3.2.1.1 Munich-Schwabing

Urban region with buildings having four to five floors, very close one to the other.

Figure 51 Google view of the Munich-Schwabing area with the position of the measurement points
Figure 52 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Munich-Schwabing
Figure 53 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Munich-Schwabing

Average power height loss from 10 m to 1.5 m: 6.5 dB (height loss is defined in ITU-R P.1546).
Table 18 Public broadcasters detected in a height of 10m; Munich-Schwabing

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
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Table 19 Private broadcasters detected in a height of 10m; Munich-Schwabing

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<tr>
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Table 20 Austrian broadcasters detected in a height of 10m; Munich-Schwabing

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5 For each location at 20 different sites the measurements were made. If e.g. at only 5 sites reception is possible, then the detection is 20%
2.3.2.1.2 Munich-Neuperlach

Urban region with high buildings, with large green areas around them.

Figure 54 Google view of the Munich-Neuperlach area with the position of the measurement points
Figure 55 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Munich-Neuperlach
Figure 56 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Munich-Neuperlach

Average height loss from 10 m to 1.5 m: 9.9 dB.
Table 21 Public broadcasters detected in a height of 10m; Munich-Neuperlach

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Table 22 Private broadcasters detected in a height of 10m; Munich-Neuperlach

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Table 23 Austrian broadcasters detected in a height of 10m; Munich-Neuperlach

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Ch 47; Cell ID 3F4
2.3.2.2 Measurement results in suburban areas of Munich

2.3.2.2.1 Munich-Freimann

Suburban region with buildings having one or two floors, surrounded by small gardens.

Figure 57 Google view of the Munich-Freimann area with the position of the measurement points
Figure 58 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Munich-Freimann
Figure 59 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Munich-Freimann

Average power height loss from 10 m to 1.5 m: 14.9 dB.
Table 24 Public broadcasters detected in a height of 10m; Munich-Freimann

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<td>Bayer. Wald</td>
<td>70</td>
<td>27</td>
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<td>Bayer. Wald</td>
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<tr>
<td>47</td>
<td>0x3008</td>
<td>Hohenpeissenberg</td>
<td>80</td>
<td>35</td>
<td>0x201</td>
<td>Munich/Wendelstein</td>
<td>100</td>
<td>28</td>
<td>0x3105</td>
<td>Regensburg</td>
<td>30</td>
</tr>
<tr>
<td>54</td>
<td>0x3002</td>
<td>Munich</td>
<td>100</td>
<td>44</td>
<td>0x20D</td>
<td>Augsburg/Hesselberg/Gelbelsee</td>
<td>100</td>
<td>46</td>
<td>0x3109</td>
<td>Grünten</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 25 Private broadcasters detected in a height of 10m; Munich-Freimann

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
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</thead>
<tbody>
<tr>
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<td>100</td>
<td>66</td>
<td>0</td>
<td>Munich</td>
<td>100</td>
</tr>
</tbody>
</table>
2.3.2.2.2 Munich-Obermenzing

Suburban region with buildings having one to four floors, surrounded by small gardens.

Figure 60 Google view of the Munich-Obermenzing area with the position of the measurement points
Figure 61 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Munich-Obermenzing
Figure 62 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Munich-Obermenzing

Average power height loss from 10 m to 1.5 m: 13.2 dB
**Table 26 Public broadcasters detected in a height of 10m; Munich-Obermenzing**

<table>
<thead>
<tr>
<th>Ch.</th>
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<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<td>28</td>
<td>0x210</td>
<td>Hohenpeissenberg/Krünten/Kreuzberg</td>
<td>100</td>
<td>25</td>
<td>0x3107</td>
<td>Augsburg</td>
<td>100</td>
</tr>
<tr>
<td>45</td>
<td>0x3009</td>
<td>Grünten</td>
<td>75</td>
<td>33</td>
<td>0x227</td>
<td>Bayerischer Wald</td>
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<td>27</td>
<td>0x3106</td>
<td>Bayerischer Wald</td>
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<tr>
<td>47</td>
<td>0x3008</td>
<td>Hohenpeissenberg</td>
<td>95</td>
<td>35</td>
<td>0x201</td>
<td>München/Wendelstein</td>
<td>100</td>
<td>46</td>
<td>0x3109</td>
<td>Grünten</td>
<td>65</td>
</tr>
<tr>
<td>54</td>
<td>0x3002</td>
<td>München</td>
<td>100</td>
<td>44</td>
<td>0x20D</td>
<td>Augsburg/Hesselberg/Gelbelsee</td>
<td>100</td>
<td>53</td>
<td>0x3108</td>
<td>Hohenpeissenberg</td>
<td>80</td>
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</table>

**Table 27 Private broadcasters detected in a height of 10m; Munich-Obermenzing**

<table>
<thead>
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<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<th>Ch.</th>
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<th>Transmitter</th>
<th>Detection %</th>
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</thead>
<tbody>
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<td>34</td>
<td>0</td>
<td>Munich</td>
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<td>Munich</td>
<td>100</td>
<td>66</td>
<td>0</td>
<td>Munich</td>
<td>100</td>
</tr>
</tbody>
</table>
2.3.2.2.3 Ebersberg

Suburban region with small buildings having one to two floors, with gardens around them. In the village center are some four floor buildings.

Figure 63 Google view of the Ebersberg area with the position of the measurement points

Figure 64 View of an Ebersberg area
Figure 65 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Ebersberg
Figure 66 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Ebersberg

Average power height loss from 10 m to 1.5 m: 14.9 dB.
### Table 28 Public broadcasters detected in a height of 10m; Ebersberg

<table>
<thead>
<tr>
<th>Ch.</th>
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<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
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<th>Cell ID</th>
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<th>Detection %</th>
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<td>23</td>
<td>0x235</td>
<td>Amberg/Ochsenkopf</td>
<td>5</td>
<td>25</td>
<td>0x3107</td>
<td>Augsburg</td>
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<td>0x3007</td>
<td>Augsburg</td>
<td>95</td>
<td>28</td>
<td>0x210</td>
<td>Hohenpeissenberg/Kreuzberg</td>
<td>10</td>
<td>27</td>
<td>0x3106</td>
<td>Bayerischer Wald</td>
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<td>0x3006</td>
<td>Bayerischer Wald</td>
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<td>0x227</td>
<td>Bayerischer Wald</td>
<td>100</td>
<td>28</td>
<td>0x3105</td>
<td>Regensburg</td>
<td>70</td>
</tr>
<tr>
<td>45</td>
<td>0x3009</td>
<td>Grünnten</td>
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<td>35</td>
<td>0x201</td>
<td>München/Wendelstein</td>
<td>100</td>
<td>39</td>
<td>0x310A</td>
<td>Untersberg</td>
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</tr>
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<td>47</td>
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<td>' '</td>
<td>70</td>
<td>42</td>
<td>0x232</td>
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<td>0x3109</td>
<td>Grünnten</td>
<td>5</td>
</tr>
<tr>
<td>54</td>
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<td>München</td>
<td>100</td>
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<td>49</td>
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<td>59</td>
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### Table 29 Private broadcasters detected in a height of 10m; Ebersberg

<table>
<thead>
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<th>Ch.</th>
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<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<th>Transmitter</th>
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<tbody>
<tr>
<td>34</td>
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<td>Munich</td>
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<td>66</td>
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<td>Munich</td>
<td>100</td>
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</table>

### Table 30 Austrian broadcasters detected in a height of 10m; Ebersberg

<table>
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<th>Cell ID</th>
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<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Salzburg-Gaisberg</td>
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<td>29</td>
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<td>Salzburg-Gaisberg</td>
<td>100</td>
</tr>
<tr>
<td>23</td>
<td>0</td>
<td>Kufstein</td>
<td>95</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Ch 22, 37, 43; Cell ID 0
Ch 47, Cell ID 3F4
2.3.2.2.4 Freising

Suburban region with small buildings having one to two floors, with gardens around them. In the village center are some four floor buildings.

Figure 67 Google view of the Freising area with the position of the measurement points

Figure 68 View of a Freising area
Figure 69 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Freising
Figure 70 Median value and standard deviation of the received power distribution in the TV channels; 1.5-m-height antenna; Freising

Average power height loss from 10 m to 1.5 m: 10.8 dB.
Table 31 Public broadcasters detected in a height of 10m; Freising

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
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<tr>
<td>36</td>
<td>0x3007</td>
<td>Augsburg</td>
<td>90</td>
<td>28</td>
<td>0x210</td>
<td>Hohenpeissenberg/Grünnten/Kreuzberg</td>
<td>95</td>
<td>25</td>
<td>0x3107</td>
<td>Augsburg</td>
<td>100</td>
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<td>0x227</td>
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<td>27</td>
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<td>Bayerischer Wald</td>
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</tr>
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<td>0x3009</td>
<td>Grünnten</td>
<td>45</td>
<td>35</td>
<td>0x201</td>
<td>München/Wendelstein</td>
<td>100</td>
<td>39</td>
<td>0x310A</td>
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<td>45</td>
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<tr>
<td>47</td>
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<td>42</td>
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<td>Untersberg/Hochberg</td>
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<td>44</td>
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<td>Augsburg/Hesselberg/Gelbelsee</td>
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<td>0x300A</td>
<td>Untersberg</td>
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</table>

Table 32 Private broadcasters detected in a height of 10m; Freising

<table>
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<th>Detection %</th>
<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<tr>
<td>34</td>
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<td>Munich</td>
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<td>48</td>
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<td>100</td>
<td>66</td>
<td>0</td>
<td>Munich</td>
<td>100</td>
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</table>

Table 33 Austrian broadcasters detected in a height of 10m; Freising

<table>
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<th>Ch.</th>
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<th>Detection %</th>
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<tbody>
<tr>
<td>32</td>
<td>0</td>
<td>Salzburg-Gaisberg</td>
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<td>29</td>
<td>0</td>
<td>Salzburg-Gaisberg</td>
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<td>Kufstein</td>
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</tr>
</tbody>
</table>
2.3.2.3 Measurement results in rural area

2.3.2.3.1 Eurasburg

Rural region with small buildings having one to two floors, with gardens around them.

Figure 71 Google view of the Eurasburg area with the position of the measurement points
Figure 72 Median value and standard deviation of the received power distribution in the TV channels; 10-m-height antenna; Eurasburg
Average power height loss from 10 m to 1.5 m: 10.3 dB.
### Table 34 Public broadcasters detected in a height of 10m; Eurasburg

<table>
<thead>
<tr>
<th>Ch.</th>
<th>Cell ID</th>
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<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
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<th>Ch.</th>
<th>Cell ID</th>
<th>Transmitter</th>
<th>Detection %</th>
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<td>36</td>
<td>0x3007</td>
<td>Augsburg</td>
<td>100</td>
<td>22</td>
<td>0x231</td>
<td>Donaueschingen/ Schwäbische Alb</td>
<td>55</td>
<td>25</td>
<td>0x3107</td>
<td>Augsburg</td>
<td>100</td>
</tr>
<tr>
<td>43</td>
<td>0x7D4</td>
<td>Ulm</td>
<td>15</td>
<td>23</td>
<td>0x234</td>
<td>Stuttgart/ Aalen/ Waldenburg</td>
<td>70</td>
<td>27</td>
<td>0x3106</td>
<td>Bayerischer Wald</td>
<td>15</td>
</tr>
<tr>
<td>45</td>
<td>0x3009</td>
<td>Grünnten</td>
<td>100</td>
<td>28</td>
<td>0x210</td>
<td>Hohenpeissenberg/ Grünnten/ Kreuzberg</td>
<td>100</td>
<td>46</td>
<td>0x3109</td>
<td>Grünnten</td>
<td>95</td>
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<tr>
<td>47</td>
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<td>Hohenpeissenberg</td>
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<td>33</td>
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### Table 35 Private broadcasters detected in a height of 10m; Eurasburg

<table>
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<tr>
<td>34</td>
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<td>Munich</td>
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<td>48</td>
<td>0</td>
<td>Munich</td>
<td>100</td>
<td>66</td>
<td>0</td>
<td>Munich</td>
<td>100</td>
</tr>
</tbody>
</table>

Ch 40; Cell ID 0
2.3.3- Conclusions of spectrum measurements in Munich area

The spectrum measurements in the Munich area show that, in addition to the six transmitters which cover the area, 2-3 times more transmitters were detected, depending on the local topography. Some of them are at more than 150 km distance. This is true for urban and rural areas.

The received power fluctuation with location has a standard deviation of about 5 to 7 dB and does not depend significantly on the antenna height (1.5 or 10 m) or the area type (urban, rural).

The average power height loss from 10 m to 1.5 m is in the range 10 to 15 dB. At first glance there seem to be an inconsistency in the results, because the values measured in urban areas are lower than the values measured in the suburban and rural areas. In urban areas buildings are mostly higher than 10 m, therefore the power measurements were taken in obstructed conditions both in 1.5 and 10 m height, and the difference is lower. In coverage calculations for urban regions, the “10 m height” is considered to be at roof-top level, being well over 10 m.

From the measurements around Munich (Ebersberg, Freising, Eurasburg) it may be concluded that the Munich city area is at least 10-20 km away from the closes coverage area of some channels. This is an enough safety distance to consider these channels as unused channels.

If we conclude that in Munich area only the found channels (including the weak channels measured in the rural area of Eurasburg) are occupied and accept adjacent channels only for low power WSD, then the availability of TVWS for channel 40-60 is described by the following figure. The actual maximum allowed power for WSD transmission for adjacent and no-adjacent channels is still under investigation, therefore a symbolic notation for y-axis is considered for illustrative proposes.

![Figure 74 TVWS available in Munich area. Symbolic notation for y-axis:](image)

There are 17 unused channels with compactness 0.184, according to the metric defined in Section 2.1.3. Following the notation of Section 2.1.3 this becomes (17; 0.184). If adjacent channels are excluded for TVWS use (in this case also channel 60 may not be used) there remain 9 channels: (9; 0.194).

However it should be considered that this is a snapshot and there may come up developments that reduce the number of Free DVB-T channels for WSD usage:

- PMSE use is not considered in this picture;
- TV channels above 60 will be cleared and the used channels will move to channels below 60;
- If DVB-T2 will be introduced there will be a simulcast phase with a high channel requirement;
- If HDTV will be broadcasted then one complex may no longer accommodate the same number of programs which means more channels are required;
• At the lower end of TV bands PSSS (Public Safety and Security Services) demand part of the spectrum. If this happens then also from the lower end TV channels will be shifted to the remaining band.

The maximum allowed transmit power in each unused channel will be computed using the methodology described in section 2.1 in T6.5.1.
### 2.3.4 Impact of mobility on sensing DVB-T signals

This section illustrates the impact of mobility on sensing of DVB-T signals based on measurements. The measurement setup is composed by a computer that controls an Advantest R313A spectrum analyzer via GPIB cable. The spectrum analyzer configuration parameters set is: resolution bandwidth 30KHz, video bandwidth 10 KHz and sweeping time 80ms.

In this study the spectrum analyzer emulates a simple energy detector with configurable detection threshold \((TH)\). The receiver antenna is a small discone antenna with an omnidirectional characteristic in horizontal plane, and bandwidth from 70 MHz to 3GHz. The power values reported are the levels at the antenna port, and are corrected for cable losses, and amplifier losses. Figure 75 shows the measurement setup.

In Portugal, Portugal Telecom is operating a Single Frequency Network for DVB-T in channel 67 (838-846 MHz) using 64 QAM modulation and FEC 2/3. Figure 76 presents the spectrogram measured during a period of 30 minutes on the roof of a 3 floor university’s building in Castelo Branco city - Figure 75. The closest DVB-T transmitter is 65 Km away. Measurements collected at the roof level showed a very stable DVB-T activity on channel 67. On the adjacent channels (66 and 68) there is no spectrum activity licensed in Portugal up to now.

Spectrum occupancy is determined when the power level exceeds a threshold previous defined \((TH)\). The choice of the threshold is a trade-off between probability of detection \((Pd)\) and probability of false alarm \((Pfa)\). For the definition of miss detection and false alarm probabilities see COGEU D3.1, Section 5.2.2.

In this measurements, the \(Pfa\) is computed examining the adjacent channels, where the DVB-T signal is absent. In this site, due to the good propagation conditions between the broadcast tower and the receiver antenna a \(Pd = 100\%\) and \(Pfa = 0\%\) is registered for a \(TH = -90\) dBm.

![Figure 75 View from the outdoor measurement site (stationary environment)](image_url)
Mobility changes the propagation channel between the DVB-T transmitters and the WSD (White Space Device) antenna. In fact, if a WSD is moving, the TV signal could be shadowed by obstacles, causing temporary signal drops, the duration of which depends on the WSD speed and propagation scenario, leading to the well known “hidden terminal problem”, detailed in D2.1. Figure 77 shows the spectrum measured by an omni antenna mounted on the car roof (1.8 m height) and moving at 30 Km/h during 30 minutes in the urban scenario of Castelo Branco city. The “white area” in Figure 77 means that the DVB-T signal was not detected with the $TH$ level specified, i.e., -90 dBm, -95 dBm or -100 dBm. For each $TH$ the $Pd$ and the $Pfa$ is computed for the entire period of measurement collection and the results showed in the following table.

Table 36 Impact of threshold level on probability of detection and probability of false alarm.

<table>
<thead>
<tr>
<th>$TH$</th>
<th>$Pd$</th>
<th>$Pfa$</th>
</tr>
</thead>
<tbody>
<tr>
<td>-90 dBm</td>
<td>62%</td>
<td>0%</td>
</tr>
<tr>
<td>-95 dBm</td>
<td>85%</td>
<td>3%</td>
</tr>
<tr>
<td>-100 dBm</td>
<td>99%</td>
<td>11%</td>
</tr>
</tbody>
</table>

Decreasing $TH$ level, the $Pd$ increases but, at the same time, the $Pfa$ also increases due to noise fluctuation registered in the adjacent channels that are free of any radio activity.

Figure 77 Spectrum measurements obtained by an omni-directional antenna mounted on the car roof for different threshold levels.
In order to illustrate how mobility change the received power and may influence the ability of a WSD to
detect the presence of primary users, Figure 78 shows the received power as a function of time for a 10
minutes route in Castelo Branco city. The aerial view of the scenario and the route are depicted in
Figure 79.

On the bottom of Figure 78 a time frame for a virtual WSD operating in DVB-T channel 67 is shown. It is
considered a time frame structure with 2 seconds time slot for sensing followed by 58 seconds of
secondary data transmission. Every minute the sensing is repeated with TH=-90 dBm. The time slots in
red corresponds to WSD transmissions due miss detections of the DVB-T signal, i.e., when the power
level is lower than -90 dBm. Note that with a real WSD, these miss detections would cause harmful
interference with the DVB-T system.

However, if the decision making process exploits past experience, the cognitive WSD can easily reject
channel 67 from the list of potential available channels for TVWS operation, avoiding interference with
the DVB-T system. Note that when the first interference event occurs (at 240 s) the channel was already
measured as occupied during the last 4 minutes, therefore the probability of change to a free channel
status is very low.

In summary, mobility brings spatial diversity gain to the decision making process. COGEU's
sensing algorithms, developed in WP4, will consider learning techniques able to take advantage of past
experience and mobility of WSDs.

Figure 78 Receive power level during 10 minutes route and associated time frame for a secondary
system operating in the same DVB-T channel.
Further studies of impact of mobility on sensing mechanisms will be carried out by R&S in Munich area (COGEU target) using the tool described in Section 2.3.1.2. Test drives in different scenarios and at different speeds will be carried out and results will be reported in D4.2.
2.3.5- Effectiveness of cooperative sensing in indoor environment

If an energy detector is used to decide about spectrum occupancy and white spaces opportunities, the average power is compared to some decision threshold. If the measured power in a certain frequency band is above this threshold, the energy detector will report that band as occupied. If the measured power is below the threshold in this frequency band, it will be reported as idle and could be used by a secondary user. The energy detector is the simplest spectrum sensing technique and doesn’t need any previous information about the signal to be sensed. However, the main limitation is degradation due to noise fluctuation and noise uncertainty [48].

Research studies such as [49] have shown that cooperative sensing can relax the sensitivity requirements of local detectors and allows keeping a high detection probability, even when using simple detectors like the energy detector.

This section illustrates the effectiveness of cooperative sensing based on real DVB-T measurements obtained with the same measurement set up showed in Figure 75. Measurement sites are now located inside the ground-floor of a university building with offices, labs, classrooms and long corridors (see Figure 80). Four indoor locations were selected in order to guarantee low level of shadowing correlation. Note that shadowing correlation between WSDs is an important factor when cooperative schemes are implemented. Decreased correlation increases the chance of getting a WSD with a very good channel and hence fewer users need to be polled for independent readings of the same signal. The location of the four measurement sites is shown on the building plant in Figure 80.

Spectrum occupancy was measured in the four indoor locations during 30 minutes; the results are presented in Figure 81 for $TH$ level equal to -100 dBm. Varying the $TH$ level we change the sensitivity of the energy detector. With $TH = -100$ dBm, Figure 81 shows that sensor 2 cannot detect any DVB-T activity, however, cooperative sensing between the four detectors can detect channel 67 as occupied. Note that without cooperation sensor 2 will require a sensitivity lower than -100 dBm to detect channel 67 autonomously, likely only possible by a feature detector and long detection time. Even a few cooperating WSD facing independent fades are enough to achieve practical threshold levels by drastically reducing individual detection requirements, decreasing the signal processing complexity, power consumption and required observation time.
2.4 - Summary of TVWS characterization

The focus of this chapter is the TVWS characterization in COGEU scenarios. Some of the key points mentioned in the chapter include:

- To describe TVWS in a specific area the total amount of white space available in MHz is not enough. COGEU introduces a new metric to quantify the fragmentation level of TVWS opportunities. Correlation between TVWS and population density is also considered.
- Due to the vast number of possible combinations of TV channels, locations of receivers and locations of WSD (White Space Devices), the direct measurements of TVWS is a cumbersome task. Measuring white spaces is only possible for some few locations, therefore combination with simulation models is required.
- The required parameters and the procedure to investigate the amount of TVWS using simulation is detailed. Computation of TVWS is a computational intensive task. Simplifications are proposed to get a procedure that allows estimating white spaces with a reasonable effort in a reasonable time.
- With a possible WSD transmit power of 1 W (30 dBm) a safety distance of approx 10 km is needed to protect DVB-T receivers in the border of the coverage area. A coverage area for 70% interference margin (acceptable DVB-T reception condition) together with this 10 km width for the safety belt around the coverage area will be used to calculate white spaces for each channel 40 to 60 (COGEU range).
- A strong WSD transmitter in the vicinity of a DVB-T receiver, transmitting on a different channel may corrupt the receiving abilities up to any reception becoming impossible. Measurements of the overload threshold of a DVB-T receiver in the presence of LTE signals are presented for 3 kinds of commercial DVB-T sets.
- Regarding PMSE in the TVWS estimation: with the known location of PMSE equipment, its working range, a margin for location accuracy plus a safety distance for TVWS device transmit power, a circle around each PMSE system is excluded from TVWS map.
• In the vicinity of a strong broadcast transmitter a WSD operating at a different channel may be impaired by DVB-T transmission. For the white space estimation this blocking effect can be taken into account by “punching out” the areas around strong transmitters.

• The interference analysis tool SEAMCAT (Spectrum Engineering Advanced Monte Carlo Analysis Tool), developed by CEPT, is suitable to investigate the interference between secondary systems operating in TVWS and incumbent receivers (DVB-T and PMSE).

• For LTE over TVWS scenario, SEAMCAT simulations showed that the safety distance around the DVB-T receiver increases as the probability of interference is set to lower values. Moreover, due to the fact that LTE BS are in line-of-sight with the DVB-T aerial antenna, the LTE downlink that usually limits the white space area (16 km for LTE BS and 4.5 km for LTE UE).

• Using SEAMCAT two detection approaches are simulated and compared: geo-location spectrum database vs. autonomous sensing. Autonomous sensing artificially limits the maximum transmit power allowed for WSD operation due to the high hidden node margin used to protect primary users. Therefore geo-location database allows a more efficient use of TVWS.

• SEAMCAT simulations shows that with one channel separation (8 MHz), an LTE UE can transmit 22 dBm if located at 300 m distance from a PMSE receiver without harmful interference. The safety distance can be decreased to 145 m if 2 channels separation is used. No further improvements are visible by increasing the channel separation above 16 MHz.

• SEAMCAT Technical Group (STG) analyses new features and enhancements from users contributions periodically. Two enhancements related with automatic computation of TVWS maps proposed by COGEU were approved by CEPT and will be available in the next official release of SEAMCAT.

• The Rohde&Schwarz ETL TV Analyzer is used by COGEU in the measurements campaign in Munich area. The ETL can read the DVB-T signal Cell ID even at very low power levels, permitting to find the origin of the DVB-T signals. Lab tests showed the Cell ID detection mechanism can detect a DVB-T signal down to 6 dB below the noise floor and its performance does not show any dependency on the propagation profile.

• Lab tests with Rohde&Schwarz state of the art spectrum analyzer showed that a threshold level of -110 dBm is a suitable benchmark against which COGEU improvement can be measured.

• Spectrum measurements were carried out in order to illustrate how mobility change the received power of DVB-T signals and may influence the ability of WSDs to detect the presence of primary users. It is also illustrated how sensing can exploit past experience taking advantage of spatial diversity brought by mobility.

• In an indoor environment, measurements showed that even a few cooperating WSD facing independent fades are enough to achieve practical threshold levels by drastically reducing individual sensing requirements of DVB-T signals.

• A spectrum measurement campaign in TV bands was carried out in the southern part of Germany (Bavaria), in urban, suburban and rural areas, within and around Munich. Analysis shows that there are 16 unused channels. If adjacent channels are excluded for TVWS use there remain 8 channels (64 MHz) for potential COGEU operation.
3- COGEU geo-location spectrum database specification

This chapter introduces the specification of the TVWS geo-location database for protection of incumbent systems. A background on the general aspects of spectrum database management is given. It discusses in detail the protection requirements for the different types of incumbent services. It also presents the topology of the database, interfaces, type of information populating the database, management functions as well as cross-border issues.

3.1- Introduction

A COGEU device uses geo-location for obtaining information on the TV white space availability in its locality. It requests a database for information on the existing frequency environment, that is, which frequency is allowed to use at the given location. The database will return not only the spectrum but also the transmit power that could be used for each frequency.

The databases store information on bands used by broadcasters as well as PMSE. Broadcasters transmitter sites could easily be registered in a database owing to their infrequently change. The location of broadcaster transmitters is well known in contrast to PMSE equipment, which is time and location variant in many cases. This is likely to be problematic for a database approach. A frequent updating of the database will be required in any case.

3.1.1- Regulatory activities on geo-location database

Due to the national constitution of frequency allocations, it would be advantageous to collect the data on a national basis by the appropriate administrations. The regulator operates as an authority concerning the regulatory constraints. In addition, general policies such as technical protection criteria have to be established by the regulators. These policies may vary by national utilization concepts or for local specifications, wherefore many policies could exist in parallel (standardized European or international policies are hardly conceivable). The regulator should be able to modify the policies due to changing conditions if necessary.

The provider of the database has to guarantee necessarily the database security and reliability. He has to be in a position to stop a secondary service by regulatory reason. Discussions on the suitability of usage restrictions may be necessary to manage interference. On the other hand a maximum on flexibility would be required to facilitate any sharing by primary user in favor of secondary user.

Further, the regulator is responsible for negotiations and co-ordinations in home and foreign countries regarding problems and difficulties with incompatible technologies, which may be the case for some systems in respect of WSD. In this context the regulator is also responsible for issues associated with possible harmonization options.

This section provides an overview of recent regulatory activities based on public reports and ongoing consultation process.

3.1.1.1 FCC

FCC, according to [45], requires all fixed and Mode II TV bands devices to access a database to obtain information on the available channels at their location and required all unlicensed fixed TV bands devices to register their operations in this database. FCC stated that it will designate one or more entities to create and operate the TV bands databases and, the databases will be a privately owned and operated service that unlicensed TV bands devices must contact to obtain information on channel availability at the locations where they are operated. Furthermore, in the case of fixed devices, to register their operation at those locations they must contact databases as well. In the case that multiple database administrators are selected, each device must contact a database service that the user or the manufacturer of the device selects. Database administrators are permitted to charge fees for registering fixed devices and providing lists of available channels to fixed devices and personal/portable devices. A TV bands database will be required to contain information on:

- All of the authorized services that operate in the TV bands using fixed transmitters with designated service areas, including full service and low power TV stations.
- The service paths of broadcast auxiliary point-to-point facilities.
The geographic regions served by PLMRS/CMRS operations on channels 14-20.
Regions served by the Offshore Radiotelephone Service.
The locations of cable head-ends and low power TV receive sites that are outside the protected contours of the TV stations whose signals they receive.

In addition, a TV bands database will be required to contain the locations of registered sites where wireless microphones and other low power auxiliary devices are used on a regular or scheduled basis. FCC did not establish any specific security requirements or protocols for communications between TV bands devices and the TV bands database.

FCC requires fixed and Mode II TV bands devices to re-check the database, at a minimum, on a daily basis to provide for timely protection of wireless microphones and other new or modified licensed facilities. If a device fails to make contact with its database on any given day, it will be required to cease operating at 11:59 PM on the following day. Mode II devices are also required to re-establish their location coordinates and to access a TV bands database for a list of available channels each time they are activated or moved. FCC further required that, if multiple database administrators are authorized, the database administrators are to cooperate to develop a standardized process for sharing data on a daily basis or more often, as appropriate, to ensure consistency in the records of protected facilities. Finally, FCC requires that a database administrator make its services available to all unlicensed TV bands device users on a non-discriminatory basis.

A number of enterprises proposed to FCC in order to participate in the standardization of a database, which would be utilized by WSD in UHF band. Enterprises like Comsearch [31], Key Bridge Global [32], WSdb [33], Spectrum Bridge [36], NeuStar [37], Key Bridge Enterprises [40], [41], Telcordia [43], Google [44] and Frequency Finder [45] are some of the candidate administrators for the assignment of TV Band database management. All the enterprises proposed a plan to implement the database based on the FCC rules. Information on these rules can be found in [45].

Meanwhile, in the Second Memorandum Opinion and Order adopted on September 23, 2010 [64], FCC notably eliminates the requirement that TV bands devices that incorporate geo-location and database access must also include sensing technology to detect the signals of TV stations and low-power auxiliary service stations (wireless microphones). It also requires wireless microphone users who seek to register in the TV bands databases to certify that they will use all available channels from 7 through 51 prior to requesting registration. Requests to register in the database will be public, thus allowing interested parties to weigh in on any given request. FCC is also taking steps to ensure that incumbent services are protected from interference from the use of white spaces in various ways. In particular, this Order reserves two vacant UHF channels for wireless microphones and other low power auxiliary service devices in all areas of the country. It also maintains a reasonable separation distance between TV White Space device and wireless microphone usage permitted to be registered in the database.

OFCOM in [10] and [16] identifies 5 key issues regarding the operation of the geo-location approach. The first issue is the information to be provided by the device to the database(s). OFCOM suggest that this be flexible with the device allowed to select from providing only its location through to providing location, locational accuracy, device type and preferences as to the amount of information that it receives. As the device provides additional information the database can tailor its response, in some cases allowing higher power levels. OFCOM note that this may require standardisation work around the protocols to be used.

The second issue is the information returned from the database(s) to the device. OFCOM suggest that this should be a list of frequencies and power levels for each geographical pixel or location. Alternatively, if the device has moved to a different country, the database might return the address that the device now needs to send its enquiry to.

The third issue, is the frequency of update of the database(s) and hence the periodicity with which devices will need to re-consult. Because some licensed uses of relevant frequencies might require access at short notice - for example some PMSE users - OFCOM suggest that devices be required to recheck the database at least every two hours.

The fourth issue, is the modelling algorithms and device parameters to be used to populate the database(s). OFCOM makes some detailed suggestions as to propagation algorithms, assumed device
sensitivity and methodology that would enable the database to derive the list of frequencies that could be available for cognitive devices from the information provided about licensed use.

The fifth issue is the maintenance of the database(s). OFCOM note that someone will need to develop and host the database and that costs will be incurred. OFCOM seek views as to who should be responsible for the database and on what terms, where the costs might fall and what role it would be appropriate for regulators to play.

In November 9, 2010 OFCOM released an important consultation document on how successfully launch TVWS technology using a “geolocation” database [55] focusing in detail on the specific technical and legal instruments needed.

The diagram below provides an overview of how OFCOM propose access to the white spaces based on geolocation will work in practice. Broadly, a “master” WSD will first consult a list of databases provided on a website hosted by OFCOM (1 and 2). It will then select its preferred database from this list and send to it parameters describing its location and device attributes (3). The database will then return details of the frequencies and power levels it is allowed to use (4). A master device may also signal to a “slave” device (a device that does not need to contact the database) as to the frequencies and power levels it may use when communicating with the master device (5). The database would be dependent on access to information about licensed usage in the band provided for digital terrestrial television (DTT) and programme making and special equipment (PMSE – mostly wireless microphones in this band), and algorithms specified by OFCOM to derive the frequencies and channels that devices may use. This should ensure that WSDs do not cause harmful interference to licensed users [55].

![Diagram of OFCOM proposal for WSD access to geo-location database.](image)

**Figure 82 OFCOM proposal for WSD access to geo-location database.** [55]

### 3.1.1.3 CEPT

CEPT based on [63], considers the geo-location as an approach where cognitive devices measure their location and consult a geo-location database to determine which frequencies they can use at their location. Parameters such as location accuracy and frequency of database enquiry are important. As an example, the accuracy of the location measured by a WSD installed under the control of an operator is expected to be better compared to an ad hoc installation.

CEPT indicates that the devices are not allowed to transmit until they have successfully determined from the database which channels, if any are available in their location. This requires that the initial access to the database is done either using a channel reserved for this purpose or by some other means, possibly using the ISM bands.

The geo-location database is a management system that, on the basis of information on available frequencies associated with locations in the database and location information received from WSD,
assists these devices in selecting their operational frequencies. CEPT indicates that, all the geographic area covered by a geo-location database is represented as pixels which are areas of predetermined dimensions. Each pixel is associated with a list of available frequencies and other relevant data that are provided to cognitive devices querying the database. The exact dimensions of a pixel may depend on the planning decisions made in populating the database. The main purpose of using geo-location database for WSD is to ensure that there is no harmful interference from the WSD to the protected services. This is achieved by sharing minimum amount of information between devices and the database to ensure the correct calculation of available channels.

Regarding the management of the geo-location database CEPT indicates various options. It is possible to have one or more databases and they could be provided by the regulator or third parties authorised by the regulator. If there are multiple databases they all need to provide the same minimum information about the available channels. The options are:

- Single open database for the entire country
- Multible open databases, selection by the device could be made.
- Proprietary closed database, corresponding to different types of devices
- The clearing house mode, where partitions the process and guarantees the validity of the provided information

Regarding the update frequency of the database, this is dependendent on the rate with which the protected systems parameters are altered or when new protected systems are established. This is important in the case of PMSE systems. Furthermore, the database would have to convert the information provided to the database into a list of allowed frequencies and associated transmitt powers to cognitive devices. Hence a translation must be performed between the two. It is very important that this translation is performed appropriately.

3.1.2- Various options for the geo-location database

Various types of databases are conceivable, but not every type is feasible for every intended purpose (see also [58] chapter 9.3.5.1).

- One option is a single database centrally managed for the whole of Europe. Every WSD consult this database using a pre-defined and standardized format independent on its location. The WSD needs only one address for consulting the database. This would be a very easy way for the hand-over of WSD to neighboring countries. In practice a European database will be difficult to realize due to differences in national approaches.

- Another possibility are multiple open and locally managed databases. The WSD can select its preferred database, but it has to be assured, that there is no difference in information in overlapping data sets due to the redundancy of the databases.

- A third option are proprietary “closed” databases corresponding to specific types of WSD. The manufacturers may establish a database for their own devices, optionally by cooperating with other manufacturers.

- Another option would be a hierarchical database system. The basis is a central database for the first query, subsequently referring to the appropriate local database.

Beyond that two sorts of database functionalities are conceivable:

- Only the protectable equipment and stations are registered in the database. All consequences have to be calculated by the WSD, e.g. available frequencies and allowed transmitting power.

- All the calculations are already done within the database. Therefore the WSD is able to call for the available frequencies and allowed transmitter power immediately without calculating by its own.

The next section discusses the importance of the COGEU geo-location database from a PMSE protection perspective.
3.2- Protection of PMSEs

The stability of DVB-T planning is favourable for the spectrum database approach. However, due to the unpredictability of some PMSE applications, the main constrains in the design of the geo-location database comes from the requirement to protect PMSEs. Therefore, the main focus of this section is on addressing the protection of PMSE through geo-location database access. The following is discussed in this section:

1. The situation of PMSE in European counties is given.
2. The operation environment of PMSE
3. The database for PMSE
4. Possible risks and counter-measures for protections
5. Parameters influencing the availability of white spaces

3.2.1- PMSE situation in European countries

The current situation in different European countries varies significantly. The following is an example of the different situations between Germany and the UK. In the UK a private company (JMF) manages the radio spectrum for PMSE use by order of OFCOM UK. JMF runs a database on registered PMSE applications which also allows for online licensing.

In Germany, the case is different. First, channels used by PMSE, i.e., 21 – 69, are divided into 3 categories as Table 36 shows.

<table>
<thead>
<tr>
<th>Channel</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 – 50 (except channel 38)</td>
<td>Public and private broadcast (SAB) and fixed SAP installations</td>
</tr>
<tr>
<td>51 – 60</td>
<td>Professional use (PMSE=SAB/SAP) fixed installations, rental service, music groups</td>
</tr>
<tr>
<td>61 – 69</td>
<td>license free use (may also be used by professional PMSE)</td>
</tr>
</tbody>
</table>

Moreover, in Germany, the use of PMSE is not registered in a database, neither for professional PMSE nor for license free PMSE use. Users in channels 21-60 get a light license from the regulator. The regulator knows which user got the permission for which channels at a given region but the actual use (time and location) is not known.

This assignment is valid until 2015. Then, according to the digital dividend, channels 61 – 69 will be cleared of broadcast which means that these bands may no longer be usable for PMSE. So far no decision was taken on how to treat this situation.

As can be seen, the difference is vast among member states. COGEU assumes that a database for PMSE is either available or will be built up in advance of introduction of white space using equipment.

In the past up to now, special protection for PMSE was not required because no other applications than TV, RAS and ARNS were allowed in the bands 470 -862 MHz and the PMSE users have been having a vital interest not to interfere with others as the interference is mutual. With the use of White Spaces by other applications on a non interfering basis, special care has to be taken not to jam/interfere PMSE.

3.2.2- The database for PMSEs

For PMSE, there are two categories of concerns; logistical and technical. On the logistical side, it is crucial that PMSE users who need interference protection can conveniently register their locations in the database. The registration process must be straightforward and easy to complete so that it can be done quickly. This will be especially important for users whose plans may change suddenly or who operate systems which have a nationwide (general) license [25] (Annex3R1).

The COGEU database specification is discussed in Section 3.3- of this deliverable; here it is just assumed that:
- a database exists that contains all the incumbent services (DVB-T, RAS, ARNS); PMSE as a secondary application which is to be protected as well, may be registered in that database or in separate, maybe even ad hoc databases.
- An interface exists which allows a PMSE user or equipment to apply for a free channel and to register in the database for required time and location.
- WSD can query the database.

### 3.2.3 PMSE operational environment

Usually for PMSE equipment the transmit power is not higher than 50 mW (17 dBm). This low power usually limits the largest operational distance between PMSE transmitter and receiver to a maximum of a few hundred meters. However, in a database only one location information per application is stored. Although best protection would be gained by storing the location of the receiver, in case of broadcast the location of the transmitter is stored and the receivers are protected by the coverage area [see 2.2.4]. In case of PMSE there is not ‘one scenario’ which comprehensively describes the usage of PMSE [25]:

![Image](image1)

**mobile Tx** <<< distance typ. 20-100 m >>> **fixed Rx**

Typical application: presenter, artist on stage,…

Figure 83 Use case Wireless Microphone - fixed

![Image](image2)

**mobile Rx** <<< distance typ. 20-100 m >>> **mobile Tx**

Typical application: Electronic News Gathering, touring guides

Figure 84 Use case Wireless microphone - mobile

![Image](image3)

**mobile Rx** <<< distance typ. 20-100 m >>> **fixed Tx**

Typical application: audio back channel to presenter, artist on stage

Figure 85 Use case InEar Monitoring
Examples for distributed antenna systems:
Several rooms:
- Concert halls
- Conference centres
- Broadcast / studios

Covering bigger area:
- Procession / street parade (mobile transmitter moving on a 2 km long street)
- Broadcast production; presentation (mobile transmitter moving on 4 km² area)

In deliverable D2.1 chapter 5.6.2.3 some typical scenarios for PMSE were presented:
- “Large events”
- “Breaking news”
- “Everyday report”

From the geo-location point of view, PMSE use may be mapped to two different cases:

1. **Stationary sites**, such as a theatre, studio or a concert hall/stadium. This class also covers the “large event” scenario. Typically for stationary sites the locations are well known in advance of the event. Often these sites stay in the same location and PMSE is used daily or frequently.

   In this category PMSE could be used either outdoors or indoors, but typically the locations would cover a building or a few buildings or a limited area.

   For stationary sites database entries may be seen as more or less static.

2. **Temporary sites** such as an exhibition, sports event, interview at a location related to TV Program making, etc. “breaking news” and “everyday report” scenarios are assigned to this. The nature of this use is temporary, time or place of PMSE use may be known only short time ahead of use. In this case the PMSE could also be used either indoors or outdoors, in fixed or mobile manner.

   For temporary sites database entries may change within short periods of time (days, hours, minutes…), due to changes of PMSE use.

**3.2.4- Possible risks and counter-measures for protection**

When considering detrimental factors to the operation of PMSE in a geo-location-database environment, all relevant system elements have to be considered:
- The PMSE equipment, to be protected from harmful interference
- The geo-location database
- The white space devices as the possible interferer
- The connection of PMSE and WSD to the database
- A possible deliberate impairment

In the real world the given information e.g. location, intended service, transmit power etc. and the information on channel occupancy has to be processed to get the required information on available channels, acceptable transmit power etc. This data processing might be done in the database or in the WSD. Putting the intelligence into the database is more flexible for later modifications and easier to supervise.

Hence here it is assumed that the data processing is implemented in the database: a WSD applying for a free channel delivers its location and maybe some other information to the database and gets back the channel to be used (if available).

### 3.2.4.1 PMSE equipment

The PMSE user itself has to take precautions against interference by registering in the database. The user should inform the database on its location and the type of service (indoor/outdoor, stationary or mobile transmitter/receiver; see section 3.2.3- on operational environment). This information enables the database to estimate the operational area. If the PMSE equipment will operate in a larger area (e.g. events like Tour de France) the database has to be informed. Database may take this into account by enlarging the operational area.

Also information on beginning and end of PMSE operation must be supplied to the database.

### 3.2.4.2 Geo-location database

The database contains information on the services to be protected. For the case of broadcast transmitters it may be assumed that modifications are extremely rare (months, even years). For the stationary use of PMSE this may similarly be true whereas in the case of temporary PMSE use changes of PMSE database entries may be more frequent (days, hours…). Mapping this short term changes into the queries of WSD the database requires updates in very short cycles (according to the protection requirements maybe hours). This may be difficult for a large, nationwide database. **To cope with this, it may be reasonable to have a “static” database for the TV transmitters (and maybe the stationary PMSE equipment) and local ad hoc databases for the temporary PMSE use.**

Moreover, as the correctness of data in the database is very crucial for the protection of the incumbents, appropriate precautions shall be taken to keep the data consistent, e.g. with plausibility checks.

**It may also be envisaged that writing to the database is only for registered users. As the modifications only affect the PMSE data, separate PMSE databases would also keep the nationwide database ‘clean’.**

### 3.2.4.3 White Space devices

To protect incumbent services, WSD are only allowed to transmit if the channel is free. In case of a sensing system the WSD therefore would “listen before talk (LBT)”. For the database system the WSD will query the database (“Ask before talk (ABT)”) to get clearance for transmission. This ABT has to be conducted periodically due to two reasons:

- The content of the database may have changed due to changes in PMSE use
- The WSD may move to a new location where the “old” data are no longer valid.

The shorter the time between database queries the better the protection of incumbents but the higher the overhead for the WSD, so the rate of database queries is a trade-off between protection needs and overhead cost.
For the white space devices a master slave configuration may be possible, where the master connects to the database and the slaves are managed by the master, without access to the database. As the slaves act like a relay that extends the operation distance of the master, care must be taken to consider this as an extended coverage in the database.

![Diagram of WSD master and slave coverage area](image)

**Figure 87 WSD master and slave coverage area.**

### 3.2.4.4 Connection to the database

The connection between a device (PMSE or WSD) and the database may be wireless or wired. The initial access can be performed through ISM bands or using a license frequency. Accidental loss of the connection cannot be excluded. Different reaction of PMSE equipment and WSD is required:

- If PMSE equipment is already registered in the database, lost connection does not influence the operation of the equipment. It may also be deliberate, e.g. the equipment may be registered in the database once and then disconnected.
- If a WSD cannot establish a connection or loses access to the database then transmission may not be started or has to be stopped immediately to avoid possible interference.

For the connection a protocol is required that enables an error free transmission of data.

### 3.2.4.5 Deliberate impairment

It is possible that someone might intentionally corrupt PMSE/database/WSD operation:

- False entries might be put into the database e.g. to prevent WSD from operation at a given location. To inhibit this, plausibility checks may be implemented or some certification might be used to avoid unauthorized access.
- Overriding/ignoring parameters returned from the database. The WSD might pretend to be at a different location to get a better channel or more bandwidth or the device might transmit with a higher power ignoring the values received from the database. This can be counteracted by a careful hardware and software design. For example, the firmware of the device needs to be secured in some way such that malicious users cannot readily download “hacks” from the Internet as has been done for popular wireless routers.

Most of these aspects are also relevant for other database applications, therefore solutions should be available.

### 3.2.5 Parameters influencing the availability of white spaces

There are, however some parameters that have a prominent role in the concept of white space use that raise open questions:

1. Location accuracy
2. Working area of a PMSE
3. Operation distance
4. Safety distance

The details of these parameters are as follows:

3.2.5.1.1 Location accuracy

To protect an incumbent device it has to be included into the database. To do so, its geographical coordinates are required. Similarly, the WSD needs its coordinates to enquire the database (if localization is not possible, database enquiry is not possible and transmission is prohibited). So, either protection (for PMSE) or operation (for WSD) is not possible if coordinates cannot be determined.

There are several ways to gain these coordinates:

- The address of the premises (not appropriate for WSD); the system can extract the coordinates from maps. Quite precise, applicable outdoor and indoor but sometimes addresses are not available or appropriate (e.g. large stadiums, countryside)
- GPS localization supplies the coordinates directly: under good conditions very accurate but so far works only outdoor
- Position finding by other wireless networks e.g. GSM using trilateration (using distances) or triangulation (using directions). Works also (mostly) indoors but with a poor accuracy.

So, location accuracy depends on the available/used technology plus additional information (e.g. such as the number of satellites visible for GPS receiver). The device may inform the database on the used technology and the database may use a look up table to ascertain the correct location accuracy. By this it can be avoided that the database always makes worst case assumptions.

3.2.5.1.2 Working area of a PMSE

To cover all operational scenarios an area of operation may be defined around the location stored in the database with a radius to be fixed. Due to the low transmit power and the short working range (20m ... 1000m) a circle around the central location can be assumed. For larger venues; e.g. street fairs and outdoor sports events, multiple locations might need to be registered. More efficient spectrum use might be possible if the database could accommodate polygonal definitions.

3.2.5.1.3 Operation distance

To protect against interference WSD have to keep an operation distance to the nearest possible PMSE receiver. This distance depends on the transmit power, signal modulation, topology etc. The distance is larger than the working area of the WSD.

3.2.5.1.4 Safety distance

To estimate the required safety distance (SD) for a WSD to a PMSE equipment these contributions have to be combined. The worst case happens when the position of the transmitter is stored in the database and the receiver is located in the direction to the interferer at its maximum distance to the PMSE transmitter:

\[ SD = \text{LA}(\text{PMSE}) + \text{WR}(\text{PMSE}) + \text{OD}(\text{WSD}) + \text{LA}(\text{WSD}) \]

Where:

- \( \text{LA}(\text{PMSE}) \): location accuracy of PMSE equipment. Example: 50 m
- \( \text{LA}(\text{WSD}) \): location accuracy of WSD. Example: 100 m
- \( \text{ID}(\text{WSD}) \): interfering distance of the WSD. Example: for \( P=1 \)W ID is approx. 10 km
- \( \text{WR}(\text{PMSE}) \): working radius of PMSE. Example: 100 m

\[ SD = 50 \text{ m} + 100 \text{ m} + 10000 \text{ m} + 100 \text{ m} = 10250 \text{ m} \]

By varying the location accuracy from 50m to 100 m it can be seen that the location accuracy has an influence of the local availability of white space effect but the total amount of white space is not reduced significantly. A careful fixing of the safety margin is a trade-off between PMSE safety requirements and local white space availability.
3.3- Specification of COGEU database

3.3.1- Purpose of the COGEU database

The main purpose of the COGEU geo-location database is to enable the protection of the incumbent systems from harmful interference. Interference can be caused by white space devices when operated in the same or adjacent channels with the incumbent systems. In order to be able to offer sufficient protection, various parameters need to be specified that will enable and help the protection process in conjunction with the overall anti-interference database design.

Unlike the current approach of unlicensed use of TVWS, currently addressed by regulators such as FCC, OFCOM and CEPT, COGEU project goes beyond the spectrum unlicensed model and proposes a secondary spectrum trading of TVWS. In COGEU model, the regulatory bodies assign TVWS for unlicensed (free) access in given areas. The remaining TVWS can be traded in a secondary spectrum market using a centralised broker.

The design of COGEU geo-location database has to deal with these two operation models. The COGEU geo-location database receives enquires from both, unlicensed WSD's and from entities running spectrum brokers. In particular, when the available TVWS are calculated, according to the regulator’s policies a percentage of these available TVWS are marked for spectrum commons access, and the remaining for spectrum market, as shown in Figure 88. When this distinction is made, COGEU geo-location database model can operate both spectrum sharing regimes. The spectrum of commons model will operate in the bands marked for unlicensed use TVWS, and the (COGEU) broker will trade the spectrum that is marked for secondary trading. An entity called spectrum commons manager will make sure that the enquiries of WSD are served from the already divided spectrum for the specific use, and an entity called Broker manager will deal with enquiries coming from the Brokers. The difference is that the Broker will request and receive batch data concerning the availability for all spectrum that is available for trading, and then the broker will use the available spectrum information efficiently through trading.

Figure 88: COGEU geo-location spectrum database and the two spectrum sharing regimes considered by COGEU: spectrum commons and secondary spectrum market.

3.3.2- COGEU database topology

Besides the information on the incumbent systems that a database will hold, it will also include the geo-location information per geographic pixel for a specific region and records of the WSD that operate in the specific region. This will lead to database information explosion. Due to the vast amount of information that the database is expected to store, a hybrid approach for the database topology design
is required. Therefore, for efficiency and better performance, COGEU geo-location database will adapt a
two level database topology as shown in Figure 89.

![Hierarchical topology with local database covering a large area (e.g. country)](image)

CDB: centralized database; LDB: Local database

The first level will contain the regulator's controlled information, which includes the incumbent system's
parameters. This information can be contained in one database that holds information per country. The
second level of information will hold the calculated geo-location information and the operating WSD
devices per specified region of control. This design also offers the flexibility of the deployment of more
than one database for one region and thus allows competitive operation of database administrators.

Moreover the proposed topology defines that the geo-location databases will be localised, which means
that there will be a database per a specific region, and if a change happen in one region the other
databases won't have to be recalculated decreasing the complexity of populating the database.

In COGEU context, unlicensed WSD of a fixed nature or portable ones that would like to operate in
TVWS need to register with a database in order to get information about possible available channels. In
order to ensure TV band database access only by accepted users or equipments, basic information
(e.g. an ID number and a serial number) will be stored during the registration process, when the vendor,
producer or owner initially registers the device with the database. When the device accesses the
database to query for available channels, it will transmit this information again for verification of
registration. This will serve as a security check.

CEPT in [62] categorise the devices based on their operation. The categories are master and slave.
Master devices are communicating with the database to retrieve operational instructions, slave devices
communicate with the database through the master device. There are two proposed modes for master-
slave operation, the first mode is when the master operates as a proxy for the slave device and access
the database for each slave device to get operation instructions, which are the available channels and
maximum allowed power. The second mode is when a master device accesses the database to retrieve
information for the area that expects the slave devices to operate and then the master device controls
the slave devices, according to the data retrieved from the database. In this case the slave devices get
their instructions only by the master device and not directly from the database.

COGEU adopts CEPT master-slave model but adds another element to the aforementioned entities that need to access
the database for information, through the introduction of the Broker entity. The Broker will be
responsible to retrieve the spectrum that is marked for trading and trade it using its own
functionalities and protocols.
3.3.3- **COGEU database interfaces**

As shown in Figure 90, the COGEU database will have six interfaces.

- **Interface A** is to provide communication with the WSD repository that operates under the spectrum of commons operations;  
- **Interface B**, is to give access to the COGEU Broker entity that will handle the secondary spectrum market;  
- **Interface C** is connected to a regulation and policies repository for the current area that the database is operating;  
- **Interface D** will be by the Incumbent systems repository which will provide information for the protected incumbent systems;  
- **Interface E** is public access interface that would enable anyone to search the Database’s non-confidential publicly available information (see more details in Section 3.3.5.4);  
- **Interface F** connects the local database with the central database in order to retrieve updates on policies and information regarding the close border areas. Each of interfaces will use IP security.

![Figure 90 COGEU interfaces with the geo-location database.](image)

3.3.4- **Physical channel for communication with the database**

In COGEU scenarios TVWS communication complements networks that use other parts of the spectrum. Therefore COGEU devices acquire white space interfaces alongside other more established radio interfaces. COGEU envisage that the initial access to the geo-location database by unlicensed
WSD (Interface A) will use existing radio interfaces such as WiFi, LTE or WiMax. Interfaces B,C,D,E and F can be wired connections through internet access. In addition, the development of detailed procedure covering all the necessary aspects of the initial and periodic connections would be desirable.

3.3.5- Populating the database

As mentioned before, the COGEU geo-location database topology consists of a hierarchy of central database (CDB) holding information for the whole country, and the local database (LDB) with regional white space information. In this section, only the information for the LDB will be given – the CDB is a simplified version of the LDB. Information from each entity identified in Figure 89 will populate the database. The details of the information populating the COGEU geo-location database are given in the following sub-sections.

3.3.5.1 Incumbent Information

As aforementioned, in order to empower the protection of incumbent systems information, the database must contain the incumbent system operation parameters. In this case, incumbent systems refer to any authorised services that operate in the TV bands using fixed transmitters with designated service areas, including full service and low power TV stations. Information about protected TV stations includes:

- Transmitter coordinates
- Effective radiated power (ERP)
- Height above average terrain of the transmitter (HAAT)
- Horizontal transmit antenna pattern (if directional)
- Channel number
- Station call sign
- Protection rules of incumbent systems (co-channel and adjacent channel protection ratios, interference tolerance)

In more detail the incumbent information that should be populated in the database is:

3.3.5.1.1 Transmitter coordinates

The absolute and relative geographic coordinates that the current station is situated. The accuracy of the information is important since the signal contour map will be produced based on the location of the transmitters.

3.3.5.1.2 Effective radiated power

In radio telecommunications, effective radiated power or equivalent radiated power (ERP) is a standardized theoretical measurement of radio frequency (RF) energy using the SI unit watts, and is determined by subtracting system losses and adding system gains. ERP takes into consideration transmitter power output (TPO), transmission line attenuation (electrical resistance and RF radiation), RF connector insertion losses, and antenna directivity, but not height above average terrain (HAAT).

3.3.5.1.3 Height above average terrain of the transmitter

Height above average terrain (HAAT) is used extensively in television network planning, as it is actually much more important than effective radiated power (ERP) in determining the range of broadcasts (VHF and UHF in particular, as they are line of sight transmissions).

3.3.5.1.4 Horizontal transmit antenna pattern

The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. The radiation pattern of an antenna is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross sections.

3.3.5.1.5 Channel number

The channel number on the UHF band where the current station transmits its signal. Each channel represents an allocated frequency in the band. The channel that a specified station transmits is defined by the rules and regulations of the local authority.

3.3.5.1.6 Station call sign
The current value is for identification purposes and uniquely identifies the DVB-T transmitter, the Cell ID. (In Section 2.3.1.1 Cell ID is used to evaluate the sensitivity of a DVB-T test receiver.)

3.3.5.1.7 Protection rules of incumbent systems
Specification of co-channel and adjacent channel protection ratios and maximum interference tolerance of incumbent systems. These parameters limit the maximum allowed transmit power of WSD and the boundaries of TV white spaces area.

3.3.5.2 PMSE systems Information
Known locations of registered sites, where wireless microphones and other low auxiliary devices are used on a regular or scheduled basis, will be included in the PMSE information entity.

Information about low power auxiliary stations like wireless microphones:
- Name of the owner
- Contact person
- Address
- Coordinates where the device will operate
- Channels used at the specified site
- Schedule of the device usage

As discussed in section 3.2, unregistered PMSE activities could pose a threat to the operation of WSDs. Therefore, in case the regulators does not allocate a specific band for PMSE, then white space users may need to include sensing to protect PMSEs. COGEU will combine geo-location database access with local sensing for protection of PMSEs.

3.3.5.3 Unlicensed WSD information
COGEU project addresses both the spectrum commons (unlicensed use) and the secondary spectrum market of TVWS. According to the COGEU reference model, the regulators will determine bands and power of the operation in the spectrum commons by allowing the WSDs to operate with specific requirements. These bands are out of the spectrum market. The remaining TVWS can be negotiated in a secondary spectrum market using a centralised broker.

Any WSDs must be registered in the database in order to be allowed to operate. There are two categories of WSDs, the fixed WSDs that operate as a master device and the personal/ portable devices that operate individually or as slave devices under a master device domain.

Information collected from fixed unlicensed WSD:
- Identifier of the WSD
- Manufacturers serial number of the WSD
- Device's coordinates (latitude and longitude)
- Location accuracy
- Name of the individual or business that owns the WSD
- Name of a contact person responsible for the device's operation
- Address of the contact person
- Email address of the contact person

The information collected from personal/ portable unlicensed TV band devices which will not register but they need only access to the database for available channels as proposed by regulators.

- Device Identifier
- Manufacturer's serial number
- Device's coordinates (latitude and longitude)

The slave devices will be some distance from the master device. As a result, they may be closer to a incumbent receiver than the master and when they transmit they may cause interference. To prevent this occurring the master device needs to inform the database of the possible distance away that slave devices may be located and the database can then take this information into account when assigning frequencies and power levels.
3.3.5.4 Broker entities information

As aforementioned, the Broker will be responsible for trading the spectrum that is marked for secondary trading. This means that the broker need to communicate with the geo-location database and request the available spectrum for trading. In order to do so, the following parameters need to be communicated by the Broker to the geo-location database to enable the database to calculate and return the parameters that the broker entity will need to operate:

- Broker Identifier
- Broker security information
- Expected area and parameters of operation (e.g. coverage are for cellular system operating over TVWS, location accuracy, …)
- Information associated to the economic transaction of buy information from the geo-location database (see COGEU business models in D2.1)

3.3.5.5 Regulatory information

The COGEU database is established and updated by national regulators or a third party authorized by the regulators and will include information such as:

1. Regulator identity,
2. Propagation algorithms and methodologies to compute TVWS maps, including protection rules and maximum allowed interference. (The database shall have the ability to be dynamically updated to continuously adjust interference protection parameters in line with the evolution of incumbent standards such as DVB-T2).
3. Information about which TVWS are for market based usage, and which are for unlicensed use in each area,
4. Regulatory policies such as Administrative Incentive Prices, Prioritization policies for Public Safety applications over TVWS, Information required to addresses European cross-border issues between national databases.
5. Regulatory control and enforcement information: the regulator should be in position to stop a secondary transmission in case of interference.

3.3.6 COGEU database management functions

This section is dedicated to the investigation and studies of important functions that should be adopted for the management of COGEU database operation.

3.3.6.1 Reporting Function

3.3.6.1.1 Computation of TVWS Maps

Incumbents sustain that if regulators publish information such as (ERP, antenna pattern, coverage, etc) to third party/externals this may undermine their business model because competition between broadcaster providers. If they would, broadcast operators in some countries (Germany, Italy) have already announced to go to the court to prevent this.

COGEU assume a realistic scenario where the regulators will not supply the sensitive data concerning broadcast transmitter parameters. Therefore, the regulator would convert the incumbent's data (confidential raw data) into a list of allowed frequencies and associated transmit powers by performing TVWS calculations like those described in Section 2.1.2. As a result of these calculations, regulators may use a map with a grid size of e.g. 200 m x 200 m (‘pixel’). For each pixel and each channel the acceptable transmit power is contained in the database as shown in Figure 91.

In COGEU, these TVWS calculation for the Munich area will be performed based on the data given by Germany’s broadcasters and German regulator BNetzA. For the considered Munich area and a pixel size of 200 m, for each channel arrays of approx. 2000 x 2000 items will be supplied e.g. as ASCII files (in this case the whole federal state of Bavaria is covered). COGEU database will be populated by inputting these data. COGEU assumes that a database for PMSE is either available or will be built up in advance of introduction of white space using equipment. However, PMSE use in Germany is not registered. To get a realistic scenario for COGEU demonstration in Munich some assumptions have to be made on distribution of PMSE equipment. E.g. it can be assumed that broadcast production companies, Theatres, Stadiums and Universities use such PMSE systems. By estimating the number of devices used at these facilities some channels may be excluded for these locations.
3.3.6.1.2 Reported information

In the initial access the regulator needs to provide to the WSD Broker the appropriate national or regional TVWS information (e.g. maximum transmit power). This information containing only broadcast systems, are rather static in the sense that changes may occur more on a scale of years than of hours.

The inclusion of PMSE might be realized e.g. by a voluntary registering of the equipment e.g. in a separate database from where the PMSE data may be supplied to the broker (This is still an open question and hence for COGEU some assumptions are necessary). Inclusion of PMSE equipment may bring time as a further relevant parameter for availability of spectrum.

The information is divided by geographic cell of specified proportions. OFCOM recommendation is 100mx100m pixel size. COGEU will use a 200m x 200m to keep complexity in a reasonable size.

For every geographic pixel in the database the information that are needed to operate is illustrated in Table 37.

Table 38: Example of information reported by the database per pixel (latitude and longitude)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Max EIRP (dBm)</th>
<th>Validity period of the information</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>20 dBm</td>
<td>1 day (adopted from OFCOM)</td>
<td>Unlicensed</td>
</tr>
<tr>
<td>45</td>
<td>20 dBm</td>
<td>1 day (adopted from OFCOM)</td>
<td>Unlicensed</td>
</tr>
<tr>
<td>51</td>
<td>30 dBm</td>
<td>7 day</td>
<td>Spectrum market</td>
</tr>
<tr>
<td>54</td>
<td>30 dBm</td>
<td>2 day</td>
<td>Spectrum market</td>
</tr>
<tr>
<td>60</td>
<td>33 dBm</td>
<td>5 hr</td>
<td>Spectrum market</td>
</tr>
</tbody>
</table>

COGEU database will provide the “validity period of information” is a period after which a database query should be repeated. This would allow for flexibility and minimisation of the overhead if, for instance, no PMSE users are at the specific location. Note that if time validity is provided then a general update frequency is not needed (2h in OFCOM initial proposal).

In addition, requirement for sensing to be used in a specific channel can be included as an option.
COGEU approach for TVWS sharing includes both spectrum commons (unlicensed) and secondary spectrum market. In order to enable the database to serve both of these models, the regulators should divide the available channels per geographic pixel. This division determines which spectrum sharing model will use the specific channels at the specific locations. This is made possible by characterizing each entry in the geo-location information entity. The characterization is made using the operation “Mode” field, in order to make clear if a specific entry will be used by the broker or by the spectrum of commons model.

Regarding the Broker entity, when a broker requests information on available spectrum for trading, the database returns all the spectrum bands available for trading. For instance if a Broker operates in the Munich area, the Local Geo-location Database will return to the Broker all available channels for trading that are under the domain of the current local database. This procedure will be repeated at least daily or when a change in the incumbent system causes the recalculation of available channels in the area that is covered by the database. When Broker receives the information and according to the already traded spectrum, calculates according to the request the trading process that will conform with the policies that have been laid out by the regulator and its own business model.

### 3.3.6.1.3 Transaction protocols

Database enquires and downloads use appropriate protocols. **COGEU will adopt Internet-based protocols and standard enquiry languages. The proposed database access procedure includes XML through web services.** In more detail the database will expose web services though the appropriate interfaces. The transported data will include XML formatted data and by using SOAP encapsulation will be transported through HTTP. Using the above methodology, the architecture has the benefit that the access to the database is controlled, and secure, since the queries that an entity will be able to perform are predefined and preformatted. Through this process the entity that accesses the database can be authenticated and authorised according to the policies that are in place at the current time in the specific database. Also the benefit of well formatted data that can be easier to manipulate and validated is inherited through the use of XML. The database is protected to the boundaries of the exposed interfaces, simply put no entity can directly access the database and alter stored information.

An entity will be able to use the services of the database, by connecting to the appropriate exposed port of the database and using the available queries. On the other hand the respond from the database will bear the same characteristics, which will provide well formatted and easier to manipulate data to the entities. That will add the benefit of faster processing of the transported data between the databases and the querying entities. In general faster processing of the exchanged information will be possible using the proposed process.

### 3.3.6.2 Registration Function

When a white space user enrols with the Database, the Database will prompt the registrant to enter all required location and contact information into the Database using the applicable interface, and web services functions.

### 3.3.6.3 Query Function

A core function of the COGEU Database will be intended to provide a list of channels available for operation at a registered WSD or the Broker. **The COGEU devices are prohibited from transmitting until they have successfully determined from the Database which frequencies, if any, they are able to transmit on in their location.** Upon query by a white space user, the Database first will establish that the device is registered with the Database, and then determine the available channels at the WSD’s location, using the applicable interference protection requirements and the information contained in the Database described above. The Database then will return a list of available channels with allowed power levels to the WSD. In addition, when queried by blacklisted WSDs the Database will return a “no channels available” response. In the case of the Broker the database will return the batch information that indicated the tradable channels for the database operational area.

Database functions will not include resolution of claims of interference from WSDs. Only the regulator may require that the party responsible for any WSD causing interference take corrective actions or cease operating the device until the interference is resolved. In the event, that a protected entity that is properly registered with the Database or whose facility information is accurately reflected in Database makes a claim of interference to the regulator, WSD will be provided identifying information upon request by the regulator.
3.3.6.4 Public Access Interface
In the proposed approach it is anticipated that a database manager should be able to manage the data for any person interested in finding available TVWS frequencies. Thus, consistent with a core mission of making publicly available information easily searchable, the proposed Database includes a public, automatic interface (shown as Interface E in Figure 89) that would enable anyone to search the Database’s non-confidential publicly available information. Making the Database generally accessible to the public will help ensure continued innovation in TVWS spectrum. Any individual or entity would be able to access and review the data. The public interface would not impact the registration and query functions of the Database, but rather would complement the open and transparent nature of the TVWS access.

3.3.6.5 Security function
The primary tasks of the security design are to ensure that a WSD or the Broker is receiving accurate channel information from an authorized source, is not able to be spoofed or to receive invalid or altered channel information from someone impersonating a Database Administrator, and to avoid corruption of the operation of the Database in performing its intended functions. With this design, both WSDs and Broker can be certain that they are communicating with a legitimate database and that information from the database cannot be altered during transmission. WSDs also can determine that they are receiving accurate channel availability information on which to base transmissions. The security design for the Database thus focuses on the Internet-facing interfaces by which Broker and WSDs communicate with the Database, shown on Interface B and Interface A in Figure 89, and encompasses several distinct mechanisms, namely public key infrastructure and transport security. The following are the details of the two mechanisms.

3.3.6.5.1 Public Key Infrastructure
A public key infrastructure ("PKI") scheme will be used by COGEU in order to authenticate with the Database. This is the same technology used on the Internet to perform transactions of all types including financial transactions. The database will present a certificate signed by a well-known certificate authority. The WSD/Broker will be able to use that certificate to validate that it is talking with the database.

3.3.6.5.2 Transport Security
The interface between a WSD and the Database and the interface between a Broker and the Database will require transport-layer security to guarantee integrity and authentication of data. Because these interfaces may be defined as HTTP interfaces carrying XML documents, the same security used for the transport of web connections may be reused for the Database. This technology (Transport Layer Security or TLS, formerly referred to as Secure Sockets Layer or SSL) provides authentication, integrity, and confidentiality properties at the transport layer below HTTP. COGEU will propose the Database to implement the TLS client and server functionality. Since security in not addressed by COGEU this will be addressed in use case level.

All communication with the TV bands database is via Web services, which provide interoperable protocols for Security, Reliable Messaging, and Transactions in loosely coupled systems. As background, a Web service is a self-contained, self-describing modular application published, discovered, and invoked over a network using standard protocols. Several open standards fully describe a web service:

- XML (Extensible Markup Language) typically encapsulates data while JSON (JavaScript Object Notation) is growing in popularity
- SOAP (Simple Object Access Protocol) or REST (Representational State Transfer) to transfer the data
- WSDL (Web Services Description Language) described how to interface with a web service
- UDDI (Universal Description, Discovery and Integration) publishes the services for general availability

This solution incorporates a standards compliant implementation of Web Services Security (WS-Security) to protect both client and server applications and enable them to communicate across the Internet Domain.
3.3.6.6 Device management function

In order to aid COGEU Database’s ability to manage enrolled devices, a white space user will support the capability to authenticate itself to the Database through a shared secret. This secret will be established between the WSD and the Database at time of enrolment. The exact process by which the Database and WSD arrive at a shared secret will be at the operational discretion of COGEU, although a common username and password type of system may be used. This shared secret may then be used to confirm that a device is enrolled with the Database.

3.4- Geo-location cross-border issues and European harmonization

It is important that the specification of such a database addresses European cross-border issues which will vary greatly from country to country (e.g. Germany with 9 neighbors to co-exist with and Ireland with only one single neighbor).

There are mainly two cases leading to database cross-border problems:

a) The first one is the operation of a registered WSD in a foreign country

b) The second one is the operation of a registered WSD near the borderline

Figure 92: Cross-border issues

Figure 92 shows both cases of cross-border operation. Both, WSD a) and b), are registered for the country x. The WSD a) is operating in country z, the WSD b) is operating near the borderline in country x. The difficulty for these cross-border operations is to guarantee the access to an applicable database if there is more than one central (European) database available.

One typical situation is depicted in Figure 93 using an example of Germany and Austria. The situation demonstrates case b); a WSD (registered in Germany) is operating in channel 32 nearby the borderline between Germany and Austria. If only the national database (including only German transmitters) is checked, there would be no problem for operation of the WSD due to the large distance between the
WSD and the three German channel 32-transmitters Rhoen, Nuemberg and Dillberg. Therefore, on a national basis, the operation of the WSD would be allowed. However, an extensive interference situation will arise due to the Austrian transmitters nearby the borderline also operating on channel 32. These transmitters (Salzburg, Bad Ischl, Lend and Mauterndorf) are not registered in a national “German-only” database, but the consideration of these Austrian transmitters are indispensable for estimation of the whole interference situation. Therefore, an access to transmitter information of the neighboring country is essential.

Figure 93: Typical situation for cross-border problems

3.4.1- Difficulties and ambiguities due to cross-border issues

Case a) Operation of a registered WSD in a foreign country (e.g. country z):

- the protected services of country z have to be taken into account
- the national policies of country z have to be applied

To achieve these requirements, the WSD needs an access to the “foreign” database of country z. For this purpose two approaches are conceivable:

1) the WSD consults the database of country z directly
2) the WSD consults the “home” database, which is subsequently referring to the required database of country z

If an access to a “foreign” database is required, a high administrative effort arises. Independent from the technical realization a legal framework has to be arranged and a roaming agreement has to be established, Standardized data format is indispensable.

To consult the “foreign” database of country z directly, the WSD has to make the decision which database will be applicable. Therefore a reliable algorithm and all possible access codes have to be implemented in the devices. This leads to a very complex technology relating to the WSD design.

Case b) Operation of a registered WSD near the borderline (e.g. country x):

- it is not sufficient taking into account the protected services of country x only
- consideration of the protected services of country z near by the borderline is required
• nationally selected policies (e.g. protection criteria) have to be applied
• a buffer zone could be a solution: the database will be extended by the protected services of country z within an area near by the borderline

The buffer zone approach will raise some difficulties concerning its realization.

First at all reasonable conditions for the choice of the buffer zone have to be established. Which area will be relevant for the WSD operation near by the borderline? This question has to be discussed for minimizing the required foreign data within the “home” database. On the other hand it has to be assured, that all relevant services are incorporated into the database. Two main approaches are conceivable:

1) a fixed distance to the borderline, which is very easy to realize

2) a more complex choice of relevant services depending on the topographic conditions

Minimizing the foreign data within the “home” database will be helpful due to another fundamental problem: the development and updating of the database in the buffer zone. The “home” database is established and updated by national regulators or a third party authorized by the regulators. However the configuration and updating of the protected services of the foreign country will be much more complicated. The reliability of the foreign data will be substantially dependent on the willingness of the foreign regulators on cooperation providing these data. A stringent secret concerning the operating data is a very usual case in practice.

Another ambiguity could be the access to the policies. There may be two possibilities to fix the appropriate policies:

1) as part of the databases

2) as part of the devices

The disadvantage of the policies as part of the database is the increasing complexity of the database. An advantage would be a clear mapping of the database and the associated policies. This wouldn’t be the case for the second possibility. For this case the device itself has to choose the appropriate policy. This could be difficult in particular for a cross-border environment.

### 3.4.2 - Suitability of European harmonization

As seen in the text before the main cross-border problem is caused by decentralization of databases and policies. **One single central (European) database would facilitate the database management especially in the cross-border cases, but a central database is not conceivable due to various reasons:**

- First at all frequency allocations take place on a national basis. Beyond that the policies (e.g. protection criteria) vary by national utilization concepts or for local specifications. Therefore, the development of a national database by regulators or administrations would be the way straightforward. Centralizing the national data into one international (European) database would enable an unrestricted overview of the operating data to all participating parties. In practice no administration would be in favor to disclose the secret of their national data. But the reliability of the central database will be substantially dependent on the willingness of the regulators on cooperation providing these data.

- For national databases as well cooperation between neighboring countries will be essential. Close cooperation in the case of cross-border operation is required. The problem is solvable only by multilateral roaming agreements and international legal frameworks. **Above all a European standardized data format is indispensable for practical reasons.**
• It would also seem sensible to co-ordinate a minimum harmonised standard for the geo-location database(s) and that would allow the safe and widespread adoption of WSDs across Europe. If different database standards were to be used in different countries this would likely result in an enhanced risk of harmful interference which must be avoided.

• Even though a full European harmonization seems to be not easy to realize, bi and multilateral negotiations and co-ordinations are indispensable. In this context, harmonization options should be considered as far as possible. Therefore, some efforts concerning harmonization and European standardization should be done to a realistic extend, without touching national customs. Technical or regulatory aspects which seem practical for some harmonization options could be dealt with by a European organization like CEPT for instance.

3.5- COGEU database complexity mitigation

From the system point of view the complexity lies on the relations of the database system. The more relations exist between the data and information entities, the more complex a database system is considered to be. The COGEU database system, under investigation, operates in two different domains. One domain is the operation of the population of the geo-location database, and the other is the operation and interaction of the WSDs and Broker with the database.

3.5.1- Complexity due to database population

In Section 2.1.2 of this deliverable it was described that calculating the coverage of DVB-T transmitters is possible with available software tools, such as IRT’s FRANSY and CEPT’s SEAMCAT as long as all the required data of broadcast transmitters, topology and morphology are known and all required parameters (e.g. protection ratios) are fixed.

If however the influence of TVWS devices to the coverage degradation and hence the possible location of TVWS device operation has to be calculated, the situation becomes difficult as follows:

- If calculations are to be made in advance for all possible locations, the required time for computation is much too high and so prevents this way;
- If calculations are to be made in real time, i.e. when a TVWS device inquires the database, the response time increases with the number of parallel inquiries from different devices.

Section 2.1.2 therefore described an approach which allows calculating TVWS in advance and so enables fast response times for database enquiries. With this approach, very complex relations between the database and the frequency management software is significantly reduced.

Section 3.3.1 (COGEU database topology) proposes a hybrid structure for the database where the first level contains the regulator’s controlled information (regulator database). The second level holds the calculated TVWS maps.

Basing on its information and using the approach of Section 2.1.2 the geo-location database generates the TVWS maps for each channel. To do this,

- the coverage of each transmitter is calculated, considering interference between different broadcasters, single frequency networks, ... (for the required location probability)
- the safety distance a TVWS device has to keep towards the coverage areas is calculated

From this, database calculates maps of ‘gross’ TVWS,

- adjacent channel situation, blocking etc. are taken into account to calculate max. transmit power for TVWS device,
- possible blocking of TVWS devices in the vicinity of strong TV transmitters and maybe further aspects may be considered
- Registered PMSE systems are also considered

The generated maps (one for each channel) contain, for each pixel, the maximum transmit power for a WSD/Broker. These maps, which have the form of two dimensional mathematical arrays, are computed periodically or if changes were made in the DVB-T and PMSE systems.
3.5.1.1 DVB-T data

In the population of the database, the complexity lies in the calculation of the available channels and maximum allowed power per location. The process is computational intensive and time consuming by definition and as an example case, for DVB-T can be performed as follow:

- Determine the wanted and unwanted DVB-T received power on a given channel and in a given location.
- Determine the location probability of each considered location, without WSD, by applying a Monte-Carlo methodology or an analytic formula.
- For all the COGEU’s target channels from 40 to 60 in each location, estimate the maximum WSD EIRP on co and adjacent channels, depending on the acceptable decrease of the location probability.
- For all the channels 40 to 60 in each location, take the minimum of WSD EIRP for each frequency.
- For all locations, take the minimum EIRP computed in the surrounding location, to take into account the location inaccuracy of the WSD.

The situation with the population of the geo-location database is that it won’t be that frequently updated since a change in the DVB-T and other fixed incumbent system is relatively rare. Moreover the proposed topology defines that the geo-location databases will be localised, which means that there will be a database per a specific region, and if a change happen in one region the other databases won’t have to be recalculated. Furthermore another measure that can be considered to mitigate the frequency and calculation complexity is that not all channels need to be taken into account when there is a change and thus need for recalculation. Only the affected and adjacent channels can be recalculated, thus minimizing the calculation and eventually the time needed.

3.5.1.2 PMSE data

Time dependency is one important aspect of the datasets managed. Whereas the TV transmitter data are very static, PMSE data may show different behaviour. Some PMSE used by TV production facilities, concert halls, stadiums museums etc. may be static as well. However, other systems such as ENG, may display more dynamic behaviour which could also be unpredictable.

To avoid short update cycles for the transfer of TVWS maps to the WSD\Broker, and therefore to reduce unnecessary efforts for communication, COGEU divide the PMSE data in two classes:

- **PMSE Static:**
  PMSE equipment remaining at the same location, used over a long time, predictable. These data shall be contained in the geo-location database and do determine the TVWS maps delivered to (or retrieved by) the WSD\Broker. The data are static in the sense of weeks and months, so such a data transfer is required very rarely.

- **PMSE Non-static:**
  The non-static PMSE equipment can be registered and treated with a high priority. The protection of this PMSE equipment can be realized by applying the same safety distance as for systems in the Regulator database.

The advantages of this Static\Non static approach include:

- Longer update periods for TVWS
- Regulator controls all the parameters for protection of incumbents
- Ability to calculate TVWS maps in advance and therefore enables short response time
- No need to perform complex coverage calculation in the Broker database
- Broker database may also operate only local or regional

3.5.2 Complexity due to interaction of white space users with database

The other operational domain, that entails the interaction of database with the WSDs and the Broker, has more factors that need to be taken under consideration in order to minimise the complexity of the system. We can consider that an interaction of a WSD with the database has three stages, the initiation, the reply and the confirmation. Initiation stage is when a WSD ask from database operation instructions...
by providing its location, id and location accuracy. The reply stage which includes the available frequencies the maximum allowed power, and the time validity of the information.

The time validity value plays an important role in the expected load of the database since it defines when the WSD will re-contact database for new information. This can be varied per location pixel and according to if there might be movement from WSD or not. Here predictive or intelligent models can be used in order to avoid unnecessary request to the database. Furthermore, the reply to the WSD can contain information regarding the neighbouring location pixel of the current location of the WSD and these to be stored internally in the WSD for reference in case of nomadic movement in an extend area, although this approach has the disadvantage of unnecessary data overhead being exchanged between WSD and database. Another property that can be used towards the complexity mitigation and overhead reduction is the location accuracy. If a WSD has an accurate location extraction method that means less information can be send to WSD which will correspond to less pixel information. Also if the accuracy of the location is high that means that short range available spectrum opportunities can be used from the specific WSD to operate, which will to better spectrum allocation and utilisation.

3.5.3- Spatial resolution

The spatial resolution of the geo-location pixel map also plays an important role in the complexity factor. For the COGEU calculations a pixel of 200m X 200m has been used and a total of 10000 pixels to cover the Munich area, which the COGEU is examining. For each available channel 10000 pixel are needed with the Maximum EIRP per channel, for that specific pixel. Other practical solutions also can be considered in order to reduce the computation time and load, for instance, if parallel processing is used and as a computational system a cluster with 10 machines consisted by four cores each a significant multiprocessor power of forty cores can reduce the time and load by an important factor. Furthermore, the concept of cloud computing can be used and available computational resources from a network can be employed to reduce the calculation time and load, and thus the complexity.

3.6- Provisioning of location information of TVWS users

Annex 1 gives an overview of positioning technologies candidates for COGEU applications. In COGEU context, Assisted-GPS technology will be adopted in order to overcome problems with low signal levels, enabling also the usage of WSD in indoor environments. A-GPS provides a 5-50m precision and Time to First Fix of 5-10 s. The following table present a comparison of the most popular positioning technologies.

<table>
<thead>
<tr>
<th></th>
<th>Location Precision</th>
<th>TTFF (Time To First Fix)</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell ID+TA</td>
<td>Relatively High Low</td>
<td>~ 4 seconds</td>
<td>Requires support from MSC and HLR, or requires devices and Cell-ID DB</td>
</tr>
<tr>
<td>Network based solution</td>
<td>Depends on cell density 100-5000 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-OTD</td>
<td>Medium Precision</td>
<td>~ 6 seconds</td>
<td>Requires support from BSS, MSC and HLR. (require carrier network involvement)</td>
</tr>
<tr>
<td>Handset based solution</td>
<td>Depends on cell density 40-400 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>High Precision &quot;Sky Line of Sight&quot; 5-20 m</td>
<td>~ 10-15 minutes start 1-2 seconds updates</td>
<td>Device support (HW)</td>
</tr>
<tr>
<td>Handset based solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A-GPS</td>
<td>High Precision &quot;Sky Line of Sight&quot; 5-50 m</td>
<td>~ 10-30 seconds start 5-10 seconds updates</td>
<td>Device support (HW), GPS reference network</td>
</tr>
</tbody>
</table>

Table 39 Comparison of positioning technologies
3.7- Summary of COGEU database specification

The focus of this chapter is the specification of the COGEU geo location database. Some of the key points mentioned in the chapter include:

- The main purpose of the COGEU geo-location database is to enable the protection of the incumbent systems (DVB-T and PMSE) from harmful interference.
- The COGEU database is established and updated by national regulators or a third party authorized by the regulators.
- The topology of the COGEU geo-location database is of a two level hierarchy of central database (CDB) holding information for the whole country, and the local database (LDB) with regional white space information. With this design if a change happens in one region the other databases won’t have to be recalculated. This design also offers the flexibility of the deployment of more than one database for one region and thus allows competitive operation of database administrators.
- For the COGEU WSDs a master-slave configuration is envisage, where the master connects to the database and the slaves are managed by the master, without access to the database.
- COGEU devices acquire white space interfaces alongside other more established radio interfaces. COGEU envisage that the initial access to the geo-location database by unlicensed WSD will use existing radio interfaces such as WiFi, LTE or WiMax.
- In COGEU model, the regulatory bodies assign TVWS for spectrum commons (free access) in given areas. The remaining TVWS can be traded in a secondary spectrum market. The design of COGEU geo-location database has to deal with these two operation models. The COGEU geo-location database receives enquires from both, unlicensed WSD’s and from entities running spectrum brokers.
- The COGEU WSD Broker are prohibited from exploiting TVWS until they have successfully determined from the database which frequencies, if any, they are able to transmit on in their location.
- Regulatory enforcement: the national regulator should be in position to stop a secondary transmission in case of interference or allocate TVWS for emergency situations.
- Information on DVB-T incumbents is stable and hence suitable for the spectrum database approach. The same is the case with registered PMSEs, usually for professional applications. COGEU assumes that a database for professional PMSE is either available or will be built up in advance of introduction of white space using equipment. However, the unpredictability of unregistered PMSE applications and Electronic News Gathering, which requires protection, is the main challenge in the design of the COGEU geo-location database.
- The COGEU geo-location database is populated by: Incumbent information (DVB-T and PMSE), Unlicensed WSD information; Broker entity information; Regulatory information. Six COGEU interfaces were identified between the database and external entities.
- COGEU assume a realistic scenario where the regulators will not supply the sensitive data concerning broadcast transmitter parameters. Therefore the regulator would convert the incumbent’s data (confidential raw data) into a list of allowed frequencies and associated transmit powers by performing TVWS calculations.
- COGEU database will provide the “validity period of information” i.e. a period after which a database query should be repeated. This would allow for flexibility and minimisation of the overhead if, for instance, no PMSE users are at the specific location. Note that if time validity is provided then a general update frequency is not needed (2h in OFCOM initial proposal).
- COGEU will use a grid size of 200m x 200m to keep complexity in a reasonable size.
- Each pixel has associated an operation “Mode” field, in order to make clear if a specific entry will be used by the Broker or by the spectrum of commons model.
- All the calculations of TVWS maps are done within the database. Therefore the WSD/Broker is able to call for the available frequencies and allowed transmitter power immediately without calculating by its own.
- Time dependency is one important aspect of the datasets managed. Whereas the DVB transmitter data are very static, PMSE data may show different behaviour. To avoid short update cycles for the transfer of TVWS maps to the WSD/Broker, and therefore to reduce unnecessary efforts for communication, COGEU database divide the PMSE data in two classes: static and non static.
• The complexity of the database is due to datasets relationships, as well as the complexity of TVWS calculations which prevent ‘on the fly’ update of white spaces information. The COGEU approach is to perform the calculations in advance for static systems (DVB-T and some PMSE applications) so as to reduce complexity.
• COGEU will adopt Internet-based protocols and standard enquiry languages. The proposed database access procedure includes XML through web services.
• Cross-border issues have to be considered in the specification of the database. A single centralized European wide database is preferred, since it facilitates the database management in cross-border cases. However this is not easy since each country controls its own information on white space usage. The problem is solvable only by multilateral roaming agreements and international legal frameworks.
• It would also seem sensible to co-ordinate a minimum harmonised standard for the geo-location database(s) and that would allow the safe and widespread adoption of WSDs across Europe. If different database standards were to be used in different countries this would likely result in an enhanced risk of harmful interference which must be avoided.
• In COGEU context, assisted-GPS technology will be adopted in order to overcome problems with low signal levels, enabling also the usage of secondary systems devices in indoor environments.
4- Conclusions

This deliverable provides the general methods and information datasets for characterizing the TVWS. Therefore, D4.1 lays the foundation for the COGEU project database and for the procedures that need to be followed to identify TVWS and the necessary protection against interference, especially the parameters stored in the spectrum database, information on how and when they should be up-dated, information on the impact of secondary TVWS devices on the deployment of PMSE devices, cross border issues as well as complexity mitigation.

Moreover, an overview of practical methodologies for TVWS computation has been given. The interference analysis tool SEAMCAT was used to investigate the interference between secondary systems operating in TVWS and incumbent receivers (DVB-T and PMSE) and computation of TVWS maps in COGEU scenarios.

A benchmark of the performance of the currently available sensing tools against which any improvement can be measured, has also been investigated based on lab tests. A spectrum measurement campaign in TV bands was carried out in the southern part of Germany (Bavaria), in urban, suburban and rural areas, within and around Munich. Analysis of spectrum occupancy shows that there are 16 unused channels. If adjacent channels are excluded for TVWS use there remain 8 channels (64 MHz) for potential COGEU operation in Munich area.

Spectrum measurements were carried out in order to illustrate how mobility change the received power of DVB-T signals and may influence the ability of WSDs to detect the presence of primary users. It is also illustrated how sensing can exploit past experience taking advantage of spatial diversity brought by mobility.

Furthermore, the design of the COGEU geo location database has been detailed. For practical reasons, the COGEU database separates the commons bands from secondary trading bands. Efficiency and better performance lead to a two level hierarchical topology design of the COGEU database. The datasets that populate the database includes incumbents’ information, PMSE devices, unlicensed white space devices, broker entities, as well as regulatory information. Interfaces between the geo-location database and external entities were identified.

The main challenges in specifying the COGEU geo-location database, includes the unpredictability of unregistered PMSE activities, cross-border issues as well as updating period of the database. This deliverable provides some insights on approaches to overcome these challenges. However, these challenges deserve further investigation, especially considering the stakeholders involved. The solutions will depend on regulatory policies as well as technological solutions.

As mentioned above, the TVWS characterization as well as the specification of the geo-location database is a basis for further development. As shown in Figure 94, this deliverable will be carried over to T6.5.1, which is related to populating the COGEU database, as well as T3.1 and T3.2 which deals with the development of the COGEU reference architecture. Finally, these tasks will lead to WP7 where the COGEU demonstrator will be integrated and evaluated.

![Figure 94: Main interconnections between the work reported in D4.1 and further tasks of the project.](image-url)
Annex 1 Geo-location techniques for COGEU

In order to get location information from TVWS users of COGEU network, several related technologies have to be investigated and studied which could be adopted by COGEU system. More specifically, E911 [26] was investigated, which is a mandatory requirement for location based services [27] of cellular networks, wideband (broadband) personal communications networks, and geographic area specialized mobile radio (SMR). E911 was made by U.S. Federal Communications Commission (FCC) and specifies three most commonly used location technologies:

- stand-alone,
- satellite-based, and
- terrestrial radio-based

According to E911, the radio-based (satellite and terrestrial) technologies are the most popular ones. A typical satellite-based technology is global positioning system (GPS) [28] as well as a typical terrestrial radio-based technology is the “C” configuration of the Long Range Navigation (LORAN-C) system [29]. In general radio-based technologies typically use base stations, satellites or devices emitting radio signals to the mobile receiver to determine the position of its user. Signals can also be emitted from the mobile device to the base. Commonly studied techniques are:

- angle of arrival (AOA) positioning,
- time of arrival (TOA) positioning, and
- time difference of arrival (TDOA) positioning

All these methods require radio transmitters, receivers, or transceivers. In other words, they depend on emitting and receiving radio signals to determine the location of an object on which a radio receiver or a transceiver is attached. To make the position determination, these methods generally have the assumption that one end of the positioning system is fixed and the other end is moveable such as a mobile phone. However, the location determination capability can be either at the fixed end or at the mobile end. Generally, it is up to the system designer to decide where the final location determination capability should reside. For performance improvement, hybrid methods (various combinations of the techniques discussed or with additional techniques) are possible. The next sections give an overview of positioning technologies candidates for COGEU applications.

A.1 Positioning Technologies

A.1.1 Global Positioning System

The GPS or Global Positioning System is a satellite based system that enables receivers or terminals on terrestrial areas to gain accurate location information. The system uses a total of 24 active satellites which have been placed in six different equally spaced orbital planes with four satellites in each. This provides the terrestrial user with a view of between five and eight satellites at any time from any point on the surface of the earth. When four satellites are visible, sufficient information is available to be able to calculate the exact position.

Satellites transmit signals that are received by the GPS receivers and using this they are able to deduce their position. Each GPS satellite transmits data that includes information about its location and the current time. All GPS satellites synchronize operations so that these repeating signals are transmitted at effectively the same instant. The signals, moving at the speed of light, arrive at a GPS receiver at slightly different times because some satellites are further away than others. The distance to the GPS satellites can be determined by calculating the time it takes for the signals from the satellites to reach the receiver. When the receiver is able to calculate the distance from at least four GPS satellites, it is possible to determine the position of the GPS receiver in three dimensions.

The satellite transmits a variety of information. Some of the main elements are known as ephemeris and almanac data. The ephemeris data is information that enables the precise orbit of the satellite to be
calculated. The almanac data gives the approximate position of all the satellites in the constellation and from this the GPS receiver is able to discover which satellites are in view.

The problem with GPS for mobile phone applications is that signal levels are low, and the receiver needs to have a direct view of the satellite. This can cause problems when the phone is used in a building, or even in an urban area where a direct view of the satellite is masked. Additionally the time taken for the receiver to lock - Time To First Fix (TTFF) can be as much as ten minutes or more from switch on. This is not acceptable when emergency calls are being made as a much faster acquisition time is required. To achieve this assistance is required for the GPS receiver, thereby giving rise to the requirement for Assisted GPS.

The four main conventional GPS receiver functions are:

1) Measuring distance from the satellites to the receiver by determining the pseudoranges (code phases);
2) Extracting the time of arrival of the signal from the contents of the satellite transmitted message;
3) Computing the position of the satellites by evaluating the ephemeris data at the indicated time of arrival;
4) Calculating the position of the receiving antenna and the clock bias of the receiver by using the above data items.

Position errors at the receiver are contributed by the satellite clock, satellite orbit, ephemeris prediction, ionospheric delay, tropospheric delay, and selective availability (SA). SA is an accuracy degradation scheme to reduce the accuracy available to civilian users to a level within the national security requirements of the United States. It decreases the accuracy capability of autonomous GPS to the 100 meter (2D-RMS) level, where RMS stands for root mean square. To reduce these errors, range and range-rate corrections can be applied to the raw pseudorange measurements in order to create a position solution that is accurate to a few meters in open environments. The most important correction technique is differential GPS (DGPS). It uses a reference receiver at a surveyed position to send correcting information to a mobile receiver over a communications link. Note that SA has been turned off since May 2000.

In addition to the task of shrinking the GPS antenna to fit a typical mobile phone, a traditional autonomous GPS receiver chipset is difficult to embed in the mobile phone for three main reasons. First, its start-up time (from turning on to the initial position fix) is relatively long due to its long acquisition time of the navigation message (at least 30 seconds to a few minutes). Second, its inability to detect weak signals, that result from indoor and urban canyon operations as well as small cellular sized antennas. Third, its power dissipation is relatively high per fix, primarily due to the long signal acquisition time in an unaided application. To deal with these problems, the assisted GPS method was proposed (Figure 95).
A.1.2 Assisted GPS

The system known as Assisted GPS or A-GPS uses the mobile phone network to assist the GPS receiver in the mobile phone to overcome the problems associated with TTFF and the low signal levels that are encountered under some situations.

For A-GPS, the network provides the Ephemeris data to the cell phone GPS receiver and this improves the TTFF. This can be achieved by incorporating a GPS receiver into the base station itself, and as this is sufficiently close in position to the mobile the data received by the base station is sufficiently accurate to be transmitted on to the mobiles. The base station receiver is obviously on all the time, and will be located in a position where it can “see” the satellites.

The information provided can be either the Ephemeris data for visible satellites or, more helpfully the code phase and Doppler ranges over which the mobile has to search, i.e. ‘acquisition data’. These ranges can be estimated as the position of the mobile is bounded because it must be within the cell served by the particular base station. This technique is able to improve the TTFF by many orders of magnitude.

Assisted GPS or A-GPS is also used to improve the performance within buildings where the GPS signals are attenuated by 20 dB or possibly more. Again by providing information to the GPS receiver in the mobile it is able to better correlate the signal being received from the satellite when the signal is low in strength. Using this technique it is possible to gain considerable increases in sensitivity and some manufacturers have claimed it is possible to receive signals down to power levels of around -159dBm. The base station supplies the receiver with navigation message bits - ‘sensitivity data’.

A.1.3 Enhanced Observed Time Difference (E-OTD)

E-OTD has been finalized by the GSM standard committees (T1P1.5 and ETIS) in LCS Release 98 and Release 99. Future releases will be handled by 3GPP. E-OTD is a TDOA positioning method based on the OTD feature already existing in GSM. The MS measures relative time of arrival of the signals from several BTSs (Base Transceiver Stations). The position of the MS is determined by trilateration (Figure 96).

There are three basic timing quantities associated with this method:

1) Observed Time Difference (OTD) is the time interval observed by an MS between the reception of signals (bursts) from two different Base Transceiver Stations (BTSs). If we denote t1 as the moment that a burst from the BTS 1 is received and t2 as the moment that a burst from the BTS 2 is received, the OTD value is the time difference, i.e., OTD = t2 - t1. If the two bursts arrive exactly at the same moment, the difference is zero, i.e., OTD = 0;

2) Real Time Difference (RTD) is the relative synchronization interval in the network between two BTSs. If we denote t3 as the moment that the BTS 1 sends a burst and t4 as the moment that the BTS 2 sends a burst, the RTD value is the difference of these moments, i.e., RTD = t4 - t3. If the BTSs transmit exactly at the same moment, the difference is zero, i.e., RTD = 0. This implies that we have a synchronized network;

3) Geometric Time Difference (GTD) is the time interval measured at the MS between bursts from two BTSs due to geometry. If we denote that d1 as the length of the propagation path between the BTS 1 and the MS, and d2 as the length of the path between the BTS 2 and the MS, the GTD value can be calculated as GTD = (d2 - d1)/ c, where c is the speed of light. If the distances to the MS are the same for both BTSs, GTD = 0.

These quantities are related by:

\[ \text{GTD} = \text{OTD} - \text{RTD} \]

Since the MS knows OTD, and RTD can be measured by an additional location measurement unit (LMU) in the infrastructure, we can calculate GTD as shown in the above equation. A constant GTD value between two BTSs defines a hyperbola. Intersection of two hyperbolas determines the location of the MS.
Another method classified under E-OTD is a mixed TOA and TDOA approach. It measures the time of arrival of the signals from a BTS to the MS and to the network node LMU and uses the equation described below to derive the MS position.

There are five quantities associated with this method:

1) The observed time from a BTS to the MS (MOT) is a time measured against the internal clock of the MS;
2) The observed time from a BTS to the LMU (LOT) is a time measured against the internal clock of the LMU;
3) Time offset $e$ is the bias between the two internal clocks of the MS and LMU;
4) The distance from MS to BTS (DMB);
5) The distance from LMU to BTS (DLB).

These quantities are related by:

$$DMB - DLB = c (MOT - LOT + e),$$

where $c$ is the speed of light.

There will be one such equation for each BTS. Since there are three unknowns (MS position $x$, $y$ and clock offset $e$), at least three BTSs are required to solve for the MS location $x$ and $y$ and the unknown clock offset $e$. The position of the MS is determined by the intersection of circles centered on the BTSs common to observations made by the MS and LMUs see (Figure 97).

The E-OTD method requires a minimum of three spatially distinct BTSs. All these BTSs must be detectable by the MS. More than three measurements generally produce better location accuracy. An implementation of the E-OTD method may require an LMU to BTS ratio between 1:3 and 1:5.
A.1.4 Positioning Methods

A.1.4.1 Angle of arrival (AOA)
The angle of arrival (AOA) system determines the mobile phone position based on triangulation (Figure 98). It is also called direction of arrival in some literature. The intersection of two directional lines of bearing defines a unique position, each formed by a radial from a base station to the mobile phone in a two-dimensional space. This technique requires a minimum of two stations (or one pair) to determine a position. If available, more than one pair can be used in practice. Because directional antennas or antenna arrays are required, it is difficult to realize AOA at the mobile phone.

Figure 98 Location determination by angle of arrival (AOA).

A.1.4.2 Time of arrival (TOA)
The time of arrival (TOA) system determines the mobile phone position based on the intersection of the distance (or range) circles (Figure 99). Since the propagation time of the radio wave is directly proportional to its traversed range, multiplying the speed of light to the time obtains the range from the mobile phone to the communicating base station. Two range measurements provide an ambiguous fix and three measurements determine a unique position. The same principle is used by GPS, where the circle becomes the sphere in space and the fourth measurement is required to solve the receiver-clock bias for a three-dimensional solution. The bias is caused by the unsynchronized clocks between the receiver and the satellite. Similarly, for terrestrial-based systems, it also requires precisely synchronized clocks for all transmitters and receivers. Otherwise, a one microsecond timing error could lead to a 300-meter position error.

Figure 99 Location determination by time of arrival (TOA).
A.1.4.3 Time difference of arrival (TDOA)
The time difference of arrival (TDOA) system determines the mobile phone position based on
triangulation (Figure 100). This system uses time difference measurements rather than absolute time
measurements as TOA does. It is often referred to as the hyperbolic system because the time
difference is converted to a constant distance difference to two base stations (as foci) to define a
hyperbolic curve. The intersection of two hyperbolae determines the position. Therefore, it utilizes two
pairs of base stations (at least three for the 2-dimensional case as shown in Figure 100) for positioning.
The accuracy of the system is a function of the relative base station geometric locations.

![Figure 100 Location determination by time difference of arrival (TDOA)](image)

A.1.4.4 Cell area (or cell ID)
One simple method for mobile phone location is to use the cell area (or cell ID) of the caller as the
approximate location of the mobile phone. This results in the position error as large as the cell area. For
instance, a pico-cell could be 150 meters in radius while a large cell could be more than 30,000 meters
in radius. Therefore, this method has not demonstrated that it can achieve 100-meter accuracy reliably
even under the best of conditions.

A.1.4.5 Other methods
Other methods are based on measuring the signal strength or measuring the signal characteristic
patterns and multipath characteristics of radio signals arriving at a cell site from a caller. For measuring
the signal strength, it employs multiple cell sites to find the location. For measuring the signal
characteristic patterns, it identifies the unique radio frequency pattern or "signature" of the call and
matches it to a similar pattern stored in its central database.

Because AOA requires the installation of directional antennas or antenna arrays, TOA and TDOA have
been chosen as the current standardization choices. Of course, this may change if the next-generation
systems can be equipped with these antennas. Both TOA and TDOA are time-based measurement
technologies. They can be implemented either based on the forward (down) link signal or reverse (up)
link signal. In addition, the location determination capability can reside either at the network side or at
the mobile phone. In order to locate several base stations or cell sites, the sensitivity of the mobile
phone may need to be increased.

A.1.5 Evaluating Positioning Technologies
After a brief understanding of position determination methodologies, it is valuable to define how each
positioning method should be evaluated. A few key categories are listed below and described. There
are of course others that could be relevant depending on the location use case. Each position
determination technique has strengths and weaknesses across each dimension that will be discussed in
the following section.
Positioning Accuracy and Uncertainty
Accuracy will vary depending on environmental conditions (indoors, urban environment, signal quality, etc.). Accuracy can vary from 5-20m (GPS) to 50-5000m+ (Cell-ID). Each positioning technology will also have varying error ranges depending, again, on a broad set of environmental conditions.
Generally, the positioning industry has been driven by GPS chipset manufacturers who are motivated to provide the highest accuracy, lowest uncertainty possible location solution. GPS-level accuracy is necessary for navigation and other turn-by-turn level accuracy user cases. However, there is a wide range of LBS apps that can make do with “lower” levels of accuracy which can be provided by WiFi, Cell-ID or other hybrid approaches. Accuracy is important, but it is only one of the factors that should be considered in weighing available positioning options.

Positioning Latency or Time To First Fix (TTFF)
Positioning latency is a critical factor in driving the usability and responsiveness of a location-aware application. In the mobile application space, acquiring a location quickly is paramount to offering a compelling user experience.
Positioning latency or TTFF is most commonly associated with portable GPS receivers or Personal Navigation Devices (PNDs). Without network assistance, GPS receivers can take on the order of 5-10 minutes before a first fix. This is a function of the time required to lock on to and receive enough information from the GPS satellites in space. Assisted GPS is able to improve this fix time to 10-30 seconds by synthetically seeding the GPS receiver with network data and accelerating the GPS acquisition and position determination process. Assisted GPS still requires data exchange and computation on both a network server and on the device, making it challenging to reduce TTFF further. Other non-GPS based technologies are able to determine a location estimate in below 10 seconds (IE WiFi or Cell-ID were looking up a location in a database is all that is required).

Positioning Determination Ubiquity
A positioning technology is not useful if it is not available in the area where the mobile device is. GPS-based methods have a strong advantage here since it is a globally accessible method and will work even if the mobile device is not associated with a mobile network (there are clear disadvantages in that situation, but it could work). WiFi methods are constrained to areas where there are wireless WiFi Access Points. This is generally not a problem in urban or suburban areas (where most interesting LBS Apps are targeting).
Indoors vs. outdoors is another factor to consider. GPS, generally, does not work well inside buildings. Whereas, WiFi is most likely best suited for indoor positioning determinations.

Positioning Fallback Options
Related to positioning ubiquity and hybrid approaches, devices are expected to make the best location calculation given available information. If GPS fails, a network-based method or Cell-ID location is desired to be returned vs. a message of “failed, try again later.” The challenge is since many methods rely on base station databases, the device must optimize how the LBS App location request is handled. If the network is asked to make the location calculation (A-GPS MS-Assist), then all available network information can be used. Hybrid approaches on-device and off-device must take into consideration returning the best known position estimate in a timely manner, even if the preferred method fails.
There are also a number of device-specific dimensions that are critical to keep in mind which drive position determination implementation on device.

Device Impact (battery, CPU drain)
Assisted GPS chip performance has improved considerably over the last few years. However, receiving and processing signals from space still takes a large amount of energy. GPS antenna placement is also critical as more devices add additional RF technologies (WiFi, Bluetooth, additional cellular bands). GPS integration continues to be an important art for device manufacturers.
Most of these positioning technologies involve some level of network data connectivity that can also impact device battery life. There are a number of on-device caching solutions that are evolving for both GPS and WiFi/Cell-ID approaches which minimize the amount of network traffic required to make a position fix. However, given most LBS Applications are making use of network connections, location becomes a limited portion of App traffic.

Device Prevalence / Support
Assisted GPS was adopted by CDMA carriers to support the FCC’s E911 mandate. Qualcomm has added GPS chips to its line of core chips. This has enabled CDMA operators worldwide to deploy
innovative mobile LBS Apps leveraging A-GPS. The GSM/WCDMA world has been slow in adopting A-GPS, with forecasts of 2009-2010 being the year of broader device support. WiFi has seen relatively limited support in mobile devices to date. There are a growing set of high-end smart phones that are integrating WiFi and driving the market (namely the Apple iPhone, HTC, Nokia, RIM and others). WiFi could be viewed as a competitor to 3G data services operators are interested in up-selling users with. WiFi also creates additional technical challenges (antenna placement, additional battery draw, etc.) which continue to improve, but remains important considerations for device manufacturers.

Device Location APIs
The availability and accessibility of Location APIs on mobile devices has been spotty at best to date. RIM, Nokia and Motorola iDEN have provided device specific Location APIs that have motivated strong initial interest from developers. The Apple iPhone and Google Android Location APIs will spur additional interest ongoing. Existing J2ME (JSR-179) and BREW (IPOSDET) API exist today for a wide set of feature phones.

However, operator involvement has made it challenging for some developers to gain easy access to location. It is clear device vendors are using location as a competitive differentiator to better position their device platforms relative to others. However, universal Location APIs still remain a challenge with the fragmentation of different APIs, devices and operator policies.

A.2 Comparison of the most popular positioning technologies
The next tables present the advantages of the most popular positioning technologies and some characteristics.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell ID+TA Network based solution</td>
<td>• Available now</td>
<td>• Very low accuracy</td>
</tr>
<tr>
<td>E-OTD Handset based solution</td>
<td>• Good accuracy (~ 150 meters)</td>
<td>• High NW investment</td>
</tr>
<tr>
<td>GPS Handset based solution</td>
<td>• High accuracy</td>
<td>• Handset impact (Sw)</td>
</tr>
<tr>
<td>A-GPS Handset based solution</td>
<td>• High accuracy, No GPS limitations, Lower cost, Low power consumption</td>
<td>• Handset impact (sw+hr)</td>
</tr>
</tbody>
</table>

Table 40 Pros and cons of positioning technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Location Precision</th>
<th>TTFF ( (\text{Time To First Fix}) )</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell ID+TA Network based solution</td>
<td>Relatively High Low Depends on cell density 100-5000 m</td>
<td>~ 4 seconds</td>
<td>Requires support from MSC and HLR, or requires devices and Cell-ID DB</td>
</tr>
<tr>
<td>E-OTD Handset based solution</td>
<td>Medium Precision Depends on cell density 40-400 m</td>
<td>~ 6 seconds</td>
<td>Requires support from BSS, MSC and HLR. (require carrier network involvement)</td>
</tr>
<tr>
<td>GPS Handset based solution</td>
<td>High Precision “Sky Line of Sight” 5-20 m</td>
<td>~ 10-15 minutes start 1-2 seconds updates</td>
<td>Device support (HW)</td>
</tr>
<tr>
<td>A-GPS Handset based solution</td>
<td>High Precision “Sky Line of Sight” 5-50 m</td>
<td>~ 10-30 seconds start 5-10 seconds updates</td>
<td>Device support (HW), GPS reference network</td>
</tr>
</tbody>
</table>
A.3 Positioning technology for COGEU applications

In a general context, telecommunications standard organizations incorporate the new location technologies into their standards, whether it is GSM, UMTS, CDMA, CDMA2000, W-CDMA or TDMA. Among the technologies investigated above, TDOA, and assisted-GPS solutions are the leading contenders for the current communication systems. Besides E911 specifications, next features may include location-sensitive billing, location tracking, location-based advertisement, and information services such as navigation, weather, and points of interest. Future systems will be less and less complex while providing more convenient and attractive services.

In COGEU context, assisted-GPS technology will be adopted in order to overcome problems with low signal levels, enabling also the usage of secondary systems devices in indoor environments.
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[31]. CEPT/ECC Report 30 - Identification of common and minimal (least restrictive) technical conditions for 790 - 862 MHz for the digital dividend in the European Union.

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<th>Description</th>
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<tr>
<td>3GPP</td>
<td>3rd Generation Partnership Project</td>
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<tr>
<td>4G</td>
<td>Fourth Generation</td>
</tr>
<tr>
<td>CEPT</td>
<td>Conference of European Postal &amp; Telecommunications</td>
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<tr>
<td>CR</td>
<td>Cognitive Radio</td>
</tr>
<tr>
<td>DVB-T</td>
<td>Digital Video Broadcasting - Terrestrial</td>
</tr>
<tr>
<td>DTV</td>
<td>Digital Television</td>
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<tr>
<td>ETSI</td>
<td>European Telecommunication Standards Institute</td>
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<td>DTT</td>
<td>Digital Terrestrial Television</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>FCC</td>
<td>Federal Communications Commission</td>
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<td>GSM</td>
<td>Groupe Spécial Mobile (also, Global System for Mobile communication)</td>
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<tr>
<td>IEEE</td>
<td>The Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communications Technologies</td>
</tr>
<tr>
<td>ISM</td>
<td>Industrial Scientific and Medical (band)</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunication Union</td>
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<td>LTE</td>
<td>Long Term Evolution</td>
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<tr>
<td>OFCOM</td>
<td>Office of Communications</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
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<td>PMSE</td>
<td>Programme Making and Special Events</td>
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<td>PWMS</td>
<td>Professional Wireless Microphone Systems</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>RF</td>
<td>Radio Frequency</td>
</tr>
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<td>RRM</td>
<td>Radio Resource Management</td>
</tr>
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<td>RSPG</td>
<td>Radio Spectrum Policy Group</td>
</tr>
<tr>
<td>SAP</td>
<td>Services Ancillary to Programme making</td>
</tr>
<tr>
<td>SDR</td>
<td>Software Defined Radio</td>
</tr>
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<td>TV</td>
<td>Television</td>
</tr>
<tr>
<td>TVWS</td>
<td>TV White Spaces</td>
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<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telecommunications System</td>
</tr>
<tr>
<td>US</td>
<td>Unites States of America</td>
</tr>
<tr>
<td>USRP</td>
<td>Universal Software Radio Peripheral</td>
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<td>VHF</td>
<td>Very High Frequency</td>
</tr>
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<td>WCDMA</td>
<td>Wideband Code Division Multiple Access</td>
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<td>WiMAX</td>
<td>Worldwide Interoperability for Microwave Access</td>
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<td>WLAN</td>
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<td>WP</td>
<td>Work Package</td>
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<td>WSD</td>
<td>White Space Device</td>
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